OPTIMIZATION OF AIR CONDITIONING IN THE DATA CENTRE

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING IN MECHANICAL ENGINEERING UNDER THE FACULTY OF ENGINEERING AND TECHNOLOGY

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DECLARATION OF ORIGINALITY AND COMPLIANCE

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I hereby declare that the thesis entitled OPTIMIZATION OF AIR CONDITIONING IN THE DATA CENTRE contains a literature survey and original research work by the undersigned candidate, as a part of his MASTER OF ENGINEERING IN MECHANICAL ENGINEERING under the DEPARTMENT OF MECHANICAL ENGINEERING, studies during the academic session 2020-2022.

All information in this document has been obtained and presented in accordance with the academic rules and ethical conduct.

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This is to certify that the thesis entitled **"OPTIMIZATION OF AIR CONDITIONING IN THE DATA CENTRE":** is a bonafide work carried out by RAMESH MACHAGIRI under our supervision and guidance in fulfilment of the requirements for awarding the degree of Master of Engineering in Mechanical Engineering under Department of Mechanical Engineering, Jadavpur University during the academic session, 2020-2022.

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CERTIFICATE OF APPROVAL

The foregoing thesis, entitled "**OPTIMIZATION OF AIR CONDITIONING IN THE DATA CENTRE"** is hereby approved as a creditable study in the area of Mechanical Engineering carried out and presented by RAMESH MACHAGIRI in a satisfactory manner to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned does not necessarily endorse or approve any statement made, opinion expressed, and conclusion drawn therein but approves the thesis only for the purpose for which it has been submitted.

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TABLE AND CONTENTS

ABSTRACT

A 'Data Centre' houses a large number of server racks and carries out high speed data transfer between the racks and a large number of electronic devices (such as computers and mobile phones etc.)An efficient design of the air-conditioning system of the Data Centre is therefore an essential component of the uninterrupted functioning of the centre.This thesis deals with the estimation of heat load and system design technique for the air-conditioning of a Data Centre.

Two Data Centres of Swasthya Bhavan are considered for case study. 3D Simulation is carried using ANSYS CFD software. Simulations of the two Data Centres are very difficult because of the larger size to design, dynamics of meshing and solving by the fluent.

"K – ε" method is used for solving in the fluent. SIMPLE method is used to couple pressure and velocity.

With this case study hotspots in the server racks are identified. Temperature, Pressure & Velocity profiles are compared at different locations.

Out of the two Data Centres case study-1 is performed on old design and case study-2 performed on modified design. Modified design with higher number of vents observed that proper cooling of server racks. Hotspots are identified mainly at the bottom of the server racks.

Keywords: Data Centre and Heat load estimation

CHAPTER-1

INTRODUCTION

1) INTRODUCTION :

A 'Data Centre' is a huge computer room having a large member of powerful computer servers located at one place. Each of these server racks are connected with small visible devices such as personal desktop computers, laptops or cell phones and are processing large number of data through innumerable transactions in credit cards, shopping areas through e-booking and other information systems. For a large company, a 'data centre' may be as large as a room of 70m X 70m housing over 2000 server racks each of 1mX 1m with 2m height.

Upon transactions with external devices, each of these server racks may dissipate 2kW to 20kW of heat. As a result, cooling of a DATA Centre is most important since otherwise, large heat flux will lead to excessive temperature rise and malfunctioning of the server racks.

The most important requirement for a 'Data Centre' is to ensure its uninterrupted and zero-down time operation. Interruption in its operation in a 'Data Centre' entails high maintenance cost in the form of repairs. The cost of loss of business due to such interruptions will also be astronomically high.

Another point is that around 50% of the total power requirement of 'Data Centre' is contributed by its "cooling system".

Due to the above reasons, an optimized and effective thermal management of the 'Data Centre' is the most important function for uninterrupted, zero-downtime operation of such a system.

2) Use of CFD simulation:

CFD (Computational Fluid Dynamics) simulation technique plays a key role for any type of data centre. CFD can be used for working design and future designs also. CFD simulation reduces the cost, decreases the workload on the labour and provides detailed visualization and study. This will helps to study the dynamics of data centre like airflow, hotspots inside the data centre and heat load estimation.

For future designs before designing in practical with the help of CFD we can identify the best design and better optimization techniques. Also for the present working designs also using this CFD easily find out airflow in the false floor and hotspots, so that design can be changed by changing the server position, placing CRAC at different locations, controlling the airflow. Ultimately optimisation of cooling air will be achieved.

Smaller changes in the design that can also easily identified with CFD simulation. By changing the perforated tiles, changing the server position required optimization is achieved or not can easily visualize. No need to change the entire design.

CHAPTER-2

LITERATURE REVIEW

Qingheyao et al.[1] have studied how the air flows in a high power server room using CFD. K $-\varepsilon, RNG\ k-\varepsilon\ and\ k-\omega$, turbulence models are used for the simuation. In these three models $k-\omega$ model given accurate results compared to other. Also they found that a unique air supply directions combination is needed so that most stable velocity field and temperature distribution will be provided. Published on 30 September 2018 in Hindawi journal.

Kamran Fouladi et al.[2] have studied by reducing order flow Data centre cooling efficiency will be optimized. They used POD-ROM hybrid flow network modelling approach for simulation. With the use of this hybrid method energy and energy can be saved up to 23% and 43% respectively can be achieved with increased server utilization. Also, adjusting external design Data centre energy efficiency can be optimized with low server utilization. Finally lower flow velocities are beneficiary for energy efficiency. Published on 15 June 2017 in ELSEVIER journal.

Jinkyun Cho and Byungseonseankim[3] have evaluated air management system's thermal performance. They incorporated two performance metrics, RCI (Rack Cooling Index) and RTI (Return Temperature Index) based on these parameters they proposed aisle partition system to divide the cold aisle and hot aisle. They compared without aisle system and with aisle system improvement of 10% and 8% in RCI and RTI is observed. Finally optimization of Data centre cooling achieved by managing the air. Published on 26 April 2011 in ELSEVIER journal.

Jinkyun Cho et al.[4] have studied airflow performance of air distribution system's for optimizing the energy in high density Data Centres. They evaluated that CRAC unit's supply air temperature affects majorly the air flow efficiency. They consider without aisle and with aisle condition. Hot aisle and cold aisle without separation 18^{o} C of supply air temperature is most energy efficient. With hot-cold aisle temperature can be increased up to 22^{o} C. Also raised floor height affects air flow performance where as ceiling height has less influence. Published on 09 September 2013 in ELSEVIER journal.

Sang-Woo Ham et al. [5]have developed a server model energy consumption simulation. This model gives relationships among the server heat generation, cooling fan airflow, ambient temperature and utilization. When compared with conventional methods (hot-cold air aisle and variable air volume) this model with increasing fan energy consumption also when CRAC supply air temperature increases above 19º C consumption of cooling energy increased. Published on 30 October 2014 in ELSEVIER journal.

Yutao Sun et al. [6] have developed dual cooling system consists of vapour compression refrigeration unit connected with a separated heat pipe unit by evaporative condenser. This unit operates in three modes based on outside environment: in hot season vapour compression mode, hot to cold transition dual refrigeration mode and in cold season heat pipe mode. When compared with conventional cooling system this model consumes less energy and increased the efficiency of Data Centre. Published on 02 February 2019 in ELSEVIER journal.

Xiaolei Yuan et al.[7] have applied Phase Change Cooling (PCC) technology to cool the Data centres. This technology divided into four categories. Firstly independent heat pipe cooling: based on the temperature difference cooling demand will be known, no power transmission and no mechanical cooling which results in less use of moving and wearing parts and provide high stability. Secondly integrated heat pipe cooling system: combines heat pipe and other cooling systems. When outside environment temperature is very high this method gives greater energy consumption. Thirdly two-phase immersion cooling: This system increase the heat transfer efficiency by boiling and condensing the coolant. Finally, cold storage system: This system is suitable for newly built Data Centres. Finally by using PCC technology not only optimization of air cooling and also cost effective with less moving parts and high reliability.Published on 23 January 2021 in ELSEVIER journal.

Xin Xiong and Poh Seng Lee[8] have developed a vortex flow type arrangement for pressure outlet an alternative for conventional hot-aisle arrangement. With this vortex flow the relived back pressure increases the rack air flow rate. Inlet air velocity increased from 1.2 m/s to 2.1 m/s, when compared with conventional method. Eventually inlet air temperature and average environment temperature reduced which results in increasing the efficiency of cooling. Published on 19 July 2021 in ELSEVIER journal.

Long Phan et al. [9] have developed mixed tiles arrangement to control airflow uniformity of perforated tiles. In their study, resistance offered by the tiles is inversely proportional to the rate of airflow. So by reducing the resistance of the tiles ultimately the airflow rate will increases. For that they observed that in the cold aisle non uniform airflow distribution is found in the perforated tiles. They investigated by changing with the mixing tiles up to uniform distribution of airflow will achieve. Ultimately they evaluated by using mixed tiles arrangement airflow distribution increased. Published on 9-12 July 2017 in ASME conference.

ZhihangSong[10] has developed an active tiles arrangement for better airflow to the server racks. Active tiles means set of fans will be provided at an angle to the perforated tiles in the false floor. This fans arrangement provides swirl action to the airflow coming from the CRACs. Aerodynamic lift will be generated by the fans which will provide better movement to the computational server units. With this better cooling performance is obtained. Published on 13-19 November 2015 in ASME conference.

James W. VanGilder and Roger R. Schmidt [11]have studied on airflow uniformity through perforated tiles in raised floor. Perforated tiles plays a greater impact on airflow rate. Some tiles will give more airflow some will not. They studied 240 simulations by comparing conventional tiles in data centres and data centres with uniform air supply through the perforated tiles. With these results perforated tiles with uniform air supply has a greater possibility to increase the efficiency of cooling air to the server racks. Published on 17-22 July 2005 in ASME conference.

Yangyang Fu et al.[12] have developed a multi –domain simulation model using Modelica-based tool. They studied and compared two case studies with this model. One is using with conventional energy and another one is using with renewable energy. Conventional energy used in normal situations whereas renewable energy used in blackout situation. The case studies show that this package is able to perform various analyses, including detailed analysis of energy efficiency and control performance in normal operation, as well as emergency operation. Published on 18 June 2019 in in ELSEVIER journal.

Akhmad R.I. Mukaffi et al.[13] have conducted case study on PAU ITB Data Centre with data centre metrics and CFD simulation. They considered two data centre metrics one is Rack Cooling Index (RCI) and second metric is Power Usage Effectiveness (PUE). They found that RCI value is near to 100% where as PUE is 2.04 which is an average value. Also with the simulation results they observed open space and gap between the components. Based on the results they evaluated inefficient usage of energy. By changing the racks place and filling the gaps with partitions the PUE value comes to 1.92. Optimization of cooling energy is achieved. Published on 2017 in ELSEVIER journal.

Mohammed Faisal K and Dr.Jeoju M Issac[14]have done a case study on a Data centre with three different configurations using CFD simulation. These configurations are under floor supply with ceiling exhaust, under floor supply with horizontal exhaust and overhead supply with horizontal exhaust. The high temperatures around 50^0 C and 65^0 C are observed in under floor supply with horizontal exhaust and overhead supply with horizontal exhaust. But under floor supply with ceiling exhaust temperatures observed as 14^0 C and 26^0 C which is as per ASHARE guidelines. Published on 10, October-2015 in International Journal of Engineering Research & Technology (IJERT).

Alfonso Capozzoil and Giulio Primiceri [15] have studied a detailed analysis on present and future technologies on cooling systems of data centres. They studied Waste Heat recovery (WHR), Renewable Energy Sources(RES) and Thermal Energy Storage(TES) integration into Data Centre. They evaluated that not only for optimizing the air cooling, controlling the equipment cost by reducing mechanical components in liquid cooling and economizer based cooling higher efficiency levels can be possible to achieve. Published on 2015 in ELSEVIER journal.

S.V. Patankar[16] has studied a detailed study on airflow distribution in a data centre. He studied airflow distribution with the help of CFD simulation. In raised floor at different heights, he compared velocity vector and pressure distribution at different heights, with using different hot-cold air partitions, with temperature and velocity distributions with increased CRAC inlet air flow. These studies gives a better idea about airflow distribution in the data centres. Published on 2010 in ASME.

N.M.S. Hassan et al.[17] have done a case study on a data centre located in CQ University, Australia. They have used CFD simulation for modelling and analysing purpose. They have observed high temperature zones at computer racks along length and width at mid plane. The temperatures are satisfied with the ASHRAE guidelines. Also low pressure areas were found in near the server racks and CRAC inlets. This study will be used for evaluating the airflow rates and thermal behaviour for optimizing and designing the existing and upcoming data centres. Published on 2013 in ELSEVIER journal.

Emad Samadiani et al.[18] have studied a research on optimizing the cooling of future data centres. They suggested an open multistage solution. With open system can anyone achieve adaptable, flexible, modular, and robust though continuous growth and improvement in the cooling of data centres. Published on 2008 in ASME.

CHAPTER-3

AIR CONDITIONING OF A DATA CENTRE – ESTIMATION OF ACCURATE HEAT LOAD AND SYSTEM DESIGN TECHNIQUE

Present state of the art of a ‘Data Centre’ and its cooling load Estimation

The present state of the art involves housing the racks in a suitable layout upon a raised floor of height around 0.25m to 0.75m with the front sides of the racks facing each other. Cold and conditioned air flow upward thorough perforated tiles from below the false floor and flows through the front faces of the racks inward into these racks. The heat dissipated in each rack is carried away by the flowing cold and conditioned air which becomes hotter and emerges out from the backside of the racks. This hot air then is sucked by the “Computer Room Air-Conditioned” or RAC units and is discharged downward under the false floor.

The front sides of the server racks in between them forms the ‘Cold Aisle’ since it contains cold air coming out from the perforated tiles of the floors. The space at the back of the server racks is called ‘Hot Aisle’ since it carries the hot air that exhausts from the back of the server racks and enters the CRAC units from their topsides.

The problem of cooling and its optimization with a variation of the cooling load can be analysed in the following steps:

I. Estimation of cooling load in a ‘Data Centre’

II. Prevention of missing of hot air from the rear side of the racks with the cold air at the front side of the server racks. This phenomenon of mixing the hot air and cold air will lead to a rise of the temperature of the supply air to the server racks and will result into overheating of the server racks.

III. CFD analysis of the velocity field and temperature field as well as the distribution of pressure throughout the ‘Data Centre’ room. The CFD simulation can be used to analyse an existing ‘Data Centre’, as well as any proposed layout for a new or reconfigured ‘Data Centre’.

As on outcome of the above analysis, it is possible to detect 'hot spots' in a simulation (before the arise in reality) and also to explore ways of mitigating them.

IV. CFD analysis of the space below the false floor is also important to know the distribution of pressure, velocity and temperature in that zone. The ways to control airflow through the perforated tiles in the false floor is crucial in order to mitigate overheating or overcooling of the server racks which will result in conversation of energy and saving of electricity consumption.

Estimating cooling Loads of 'Data Centre'

Estimating cooling loads requires an understanding of the amount of heat produced by the IT equipment and by other heat sources inside the 'Data Centre'. The total cooling requirement is the sum of the heat gains from:

- Heat released inside the space viz from the IT equipment, UPS, distribution, air conditioning units, lighting and people.
- Building envelope, that is heat from the roof, walls and windows; load that varies with the outdoor environment.
- Ventilation air load that is from filtered outdoor air and infiltration; load that varies with the outdoor environment.

The worksheet below makes it easier to determine the total heat output of a 'Data Centre' quickly and reliably:

Item	Data Required	Heat Output Calculation	Heat Output Subtotal
IT equipment (Servers, Switches, Routers etc.,)	Total IT load (sum of the power inputs of all IT equipment)	Same as total IT load power in Watts, i.e., 1kW of cooling per kW of Power consumed	________ Watts.
UPS with battery	Power system rated power (Rating of UPS systems excluding redundant modules)	(0.04 X power system rating) + (0.08 X total IT load power)	________ Watts.
Power distribution	Power system rated power	(0.02 X Power system rating) + (0.02 X total IT load Power)	________ Watts.
Lighting	Floor area in square feet or square meters	2.0 X floor area in square feet	________ Watts.
People	Maximum number of personnel in 'Data Centre'	130 X number of personnel	________ Watts.
Ventilation air	A positive pressure of 0.02 $\pm$ 1 inches of water gauge is recommended	Watts = 0.03 X Q X ΔT where Q = volumetric flow rate of air in cubic feet per minute (CFM)	________ Watts.
Total Amount of cooling required Note: Every Watt equals 3.41 BTU/hour of cooling load. HVAC designers can calculate the cooling load for each piece of equipment by multiplying the number of Watts by 3.4 to produce BTU/hour. The total BTU/hour divided by 12000 determines the refrigeration capacity in Tons of refrigeration (TR)			________ Watts. X 3.41 BTU/hour {Note 1Watt = 3.41 BTU/hour)

Table -1

A typical ‘Data Centre’ has a cooling has a cooling density (heat load) of 50W to 150W per square foot. A small Data Centre’ sized for 5000 square feet how a cooling load requirement of 71 TR

$$\left[\frac{50W\ X\ 500\ ft^2\ X\ 3.412\frac{BTU}{hr}}{12000\frac{BTU}{hr}TR} = 71\ TR\right]$$

at the low end and 213 TR of cooling

$$\left[\frac{150W\ X\ 500\ ft^2\ X\ 3.412\frac{BTU}{hr}}{12000\frac{BTU}{hr}TR} = 231\ TR\right]$$

at the high end.

Example:

A typical ‘Data Centre’ also has cooling density (heat load) of 50W to 150W per sq. ft. A small ‘Data Centre’ sized for 5,000 sq. ft. is equal to [50W x 5,000 sq. ft. x 3.412 / 12000 = 71 tons of cooling] at the low end and to [150W x 5,000 sq. ft. x 3.412 / 12000 = 213 tons of cooling] at the high end.

Notes:

1. **Equipment Heat Gains** – The ‘Data Centre’ equipment name plate describes the maximum amount of cooling required. But in almost all instances, equipment load cannot be easily calculated because the information regarding the equipment to be installed is quite simply not available. Experience plays a significant role in establishing the right load density and, wherever possible, valuable information can be obtained from conducting power audits of existing facilities. For guidance, the following guidelines may be adopted for estimating preliminary cooling loads.

- Scarcely populated 20-40 Watts per sq. ft.
- Moderately populated 50-60 Watts per sq. ft.
- Densely populated 70-100 Watts per sq. ft.
- Heavily populated 100-150 Watts per sq. ft.

2. **Building Envelope Heat Gains –** A ‘Data Centre’ room gains heat due to solar loads. If the

‘Data Centre’ is located in interior spaces having no exposed wall or windows, there will be negligible heat transfer through the building envelope. However, if walls or the roof get a lot of sunlight or there are other sources of environmental heat, the HVAC designer should assess how that affects the thermal requirement. Designers need to review the materials involved in the building’s construction and select materials offering the greater insulation against transmission of heat. Solar heat gains through the windows should be eliminated by enclosing any existing windows with an insulated barrier. Additionally, any gaps that allow unnecessary infiltration/exfiltration need to be sealed and eliminated. From an energy conservation point of view, any heat gains that are not directly due to IT server equipment represent inefficiency that must be minimized.

3. **Occupancy –** Purpose built ‘Data Centres’ normally don’t have people working in them, but it is safe to assume occupancy of 2 or 3 persons. The heat output is around 100 Watts per person. For ventilation purpose the outside air intake shall be based on building pressurization of 0.02 inches of water.
4. **Lighting –** Lighting loads are normally considered at 2 Watts per sq. ft.
5. **Auxiliary Power –** The heat output of the UPS and power distribution systems consist of a fixed loss plus a loss proportional to the operating power. Conveniently, these losses are sufficiently consistent across equipment brands and models to be approximated without significant error.

COOLING EQUIPMENT

Having calculated the cooling load, the next step is to decide the capacity and number of air conditioning units. The capacity of the cooling equipment is normally specified in the BTU/hr and is often expressed in tons of refrigeration, where one ton of refrigeration corresponds to a heat extraction rate of 12,000 BTU/hr. The ton rating is very subjective because it is based on total cooling which is comprised of ‘sensible cooling’ and “latent cooling”.

- Sensible cooling is the ability to remove heat that causes a change in temperature, but no change in the moisture content.
- Latent cooking is the ability to remove moisture from the surrounding environment.

The cooling capacity stated for a comfort unit is usually its total cooling capacity (i.e., sensible + latent). But, since the electronic equipment generates only the dry heat (no moisture) the sensible cooling capacity becomes the most useful value for 'Data Centres'. The common way to express this is by the sensible heat ratio which is:

$$Sensible\ Heat\ Ratio\ (SHR) = \frac{Sensible\ Cooling}{Total\ Cooling}$$

For comfort air conditioning, the SHR IS 0.60 to 0.70; that is the coil/air flow is designed to remove 30% to 40% latent heat load (moisture) and 60% to 70% sensible heat load. The cooling equipment for the 'Data Centre' is designed for 0.85 to 0.95 SHR; that is 85% to 95% sensible heat load and 5% to 15% latent load. These units will remove the high sensible heat load produced by the electronic equipment in a 'Data Centre'.

The cooling equipment used for data centres is commonly known as "Precision air conditioning units" or "Computer room air conditioners (CRAC's)". By design these virtually deliver 100% sensible cooling and maintain the temperature within closed tolerance of $\pm 1^0$F and $\pm 3^0$F. From an air flow standpoint, these provide a very large volume of air, if we compare this equipment to a comfort air conditioning system which moves air at a rate of about 400 cubic feet per minute (CFM) per cooling ton, the CRAC units are designed to move air at about 500 and 600 cubic feet per minute (CFM) per cooling ton. This is nearly twice the amount of air. The much larger air volume contributes to good air distribution and provides a better level of filtration.

We will learn more about the precision cooling equipment and system design options in the following section.

I. Analysis of cooling load in a 'Data Centre'

The cooling load estimation is carried out in two parts.

A) **Sensible Heat** (RSH) : This includes the following:

Heat gain through walls = $A_w \times \Delta T_w \times U_w$ - - - - - - - - - - (i)

A_w = Total area of side walls

ΔT_w = Temperature difference between surrounding space of 'Data Centre and the room = $T_{surr} - T_{data\ centre}$

U_w = overall heat transfer coefficient for conduction and convection through the composite wall of the Data Centre.

Heat gain through floor= A_{floor} X ΔT_{floor} X U_{floor} - - - - - - - - - - (ii)

{similar to the above, A_{floor},ΔT_{floor} and U_{floor}refers to the are, temperature difference and overall heat transfer coefficient of the floor.

Heat gain through ceiling = A_{floor} X ΔT_{floor} X U_{floor} - - - - - - - - - - (iii)

Heat gain by Solar Radiation through sun exposed glass areas in the walls by conduction through sun exposed glass areas as well as by conduction and convection through walls of the room that are exposed to the outside.

For a 'Data Centre', since all the walls are normally not exposed to the Sun, this particular component of Heat is zero.

Sensible Heat gain from the equipment = Heat dissipation by each server rack X total number of racks (in kW) - - - - - - - - - - (iv)

Sensible Heat gain through Lights in kW.

Sensible Heat gain from persons working inside the Data Centre' = Number of persons X sensible heat gain per person - - - - - - - (v)

This component is also not appreciable.

Sensible Heat gain through outside ventilation air and infiltration air =

B) Latent Heat (RLH):

a) Due to equipment = zero (since, there are no latent heat producing units in a Data Centre')
b) Due to oven parts
c) Due to infiltration and outside air

Based on the above, the relevant conditions are plotted and with a few steps of construction on the PSYCHROMETRIC CHART as shown below, the capacity of the refrigeration plant is determined.

For By pass factor of cooling coil = 0

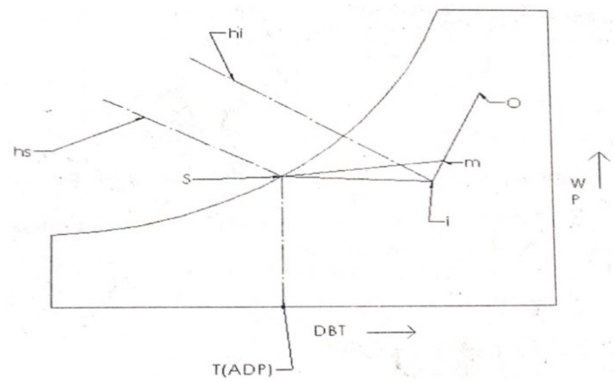


Fig :1

Total cooling Load = RSH + RLH

Cooling coils surfaces temperature = $t_s = t_{ADP}$

Mass flow rate of cold air (supply air)

$$m_s = \frac{RSH + RLS}{h_i - h_s}$$

For cooling coil By pass Factor = x

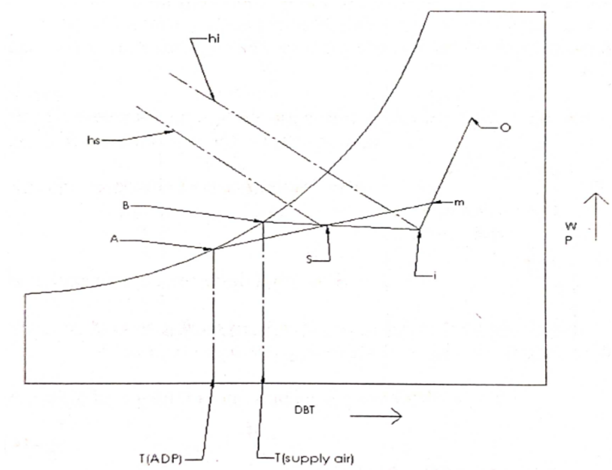


Fig : 2

LEGEND $i \equiv Data\ Center\ inside\ condition$

o ≡ 'Data Centre' outside condition

m ≡ mixture condition or inlet condition of cooling coil

s ≡   cooling coil outside condition or supply condition to the Data Centre'

p_s≡ cooling coil surface temperature t_{adp}

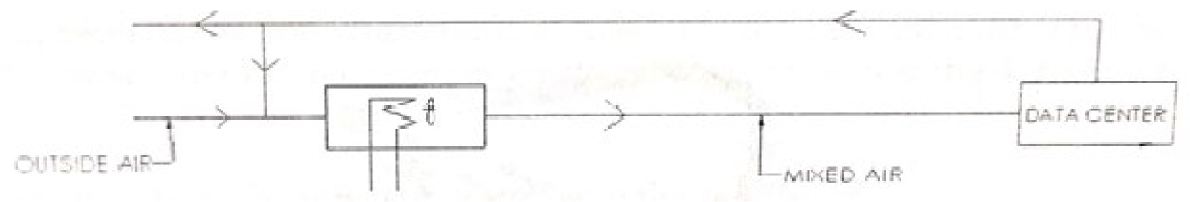


Fig :3 scheme of air circulation in data centre cooling system

The output from the cooling load calculations are summarized below

Cooling load of the DATA CENTRE [i.e., CRAC capacity] = m_s (h_i – h_s) = RSH + RLH

m_s = Mass rate of flow of supply air to Data Centre

hi = specific enthalpy of inside air

h_0 = specific enthalpy outside air of the Data Centre

RSH = Data Centre Sensible Heat Load

RLH = Data Centre Latent Heat Load

Cooling coil surface temperature, t_{ADP} = t_{coil}

Mass flow rate of supply air from CRAC

$$m_s = \frac{RSH + RLH}{h_i - h_o}$$

Bypass Factor of Cooling coil of CRAC

$$x = \frac{t_s - t_{coil}}{t_m - t_{coil}} = \frac{h_s - h_{coil}}{h_m - h_{coil}}$$

II. Effective isolation of Hot Air from the Server Racks from the cold air (to be supplied) to the Server Racks

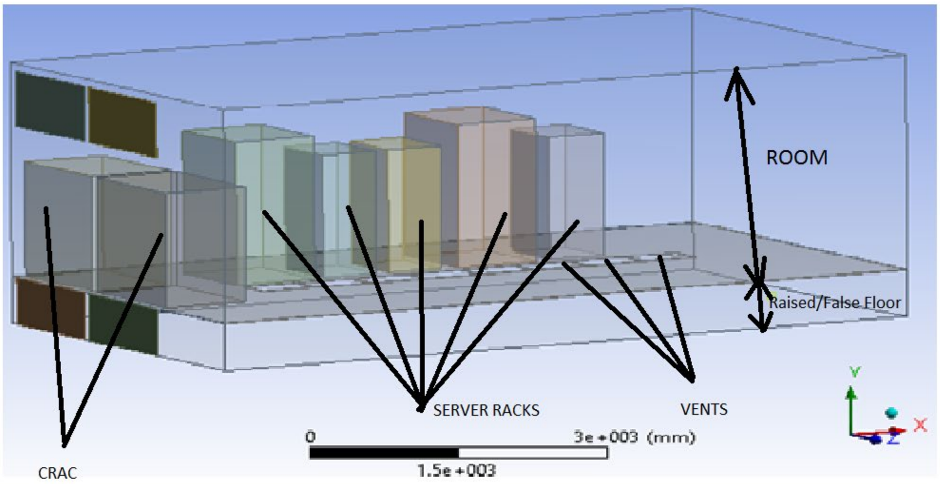


Fig :4 Data centre with Raised floor, Servers, CRACs and Vents

The missing of Hot Air from the Hot Air Isle and cold Air from the COLD AIR ISLE poses a serious threat to the cooling of the server racks. As a result of insufficient cooling, the rack temperature rises beyond control and such situation may lead to failure of the data centre causing interruption in service.

As a remedy, it is suggested to fabricate Hot Air Duct (Return Air Ducting) made of aluminium sheets conforming to IS;655 from the backside of the server rack to the top (inlet) of the CRAC.

Some Important parameters that influence the maximization of cooling system performance:

The key temperature measure at the inlet of the rack is a function of the geometrical layout of the Data Centre. Ideally, the temperature at the inlet of the racks should be equivalent to the next tile inlet or CRAC temperature, henceforth referred to T_r. However due to infiltration of hot air from the hat aisles and recirculation of exhaust air from the racks the rack inlet air temperature is typically higher than the vent tile inlet temperature. Similarly, the hot exhaust air temperature from the racks, and the hot aisles should be equal to the CRAC return air temperature e.g. if a duct was provided that picked up all the hot air from the hot aisle and returned it back to the CRAC inlet. However due to infiltration of cool air from the vent tiles and the cold aisles, the return air temperature to the CRAC is not equal to the exhaust air temperature from the rack. Yet another phenomenon is the "short circuiting" of this vent tile overflow back to the CRAC return. Thus, a study may be done on examining the flow of and the thermal behaviour of the return air to the CRAC and the rack inlet air.

Thus, the objective of determining the parameters for maximization of cooling system performance.

To minimise the infiltration of hot air into the cold aisle

Minimise the mixing of hot return air with cold air streams, prior to return to the CRAC units.

Minimising the short circuiting of cold air to the CRAC inlet.

Development of the Two parameter Supply Heat Index (SHI) and Return Heat Index (RHI)

The total heat dissipation from all the racks in the Data Centre is given by

$$Q = m_r \ C_{P_a}\left[T_{r_{out}} - \ T_{r_{in}}\right] \ ---------- (1)$$

Where m_r = Total mass flow rate of air through the racks

$$T_{r_{out}} \ and \ T_{r_{out}} \ are \ respectively \ the \ average \ outlet \ and \ inlet \ temperatures$$

$$of \ air \ into \ and \ out \ of \ the \ racks$$

$$C_{P_a} = specific \ heat \ of \ air \ at \ constant \ pressure$$

Again the rise in enthalpy of the cold air before entering into the racks of the coming out of the vent tiles is given by

$$dQ = m_r \ C_{P_a}\left[T_{r_{out}} - \ T_r\right] \ ---------- (2)$$

Where T_r = Vent tile inlet air temperature

Now, the "Supply Heat Index" (SHI) for the Data Centre is given by

$$SHI = \frac{\partial Q}{Q + \partial Q} = \frac{Enthalpy\ rise\ due\ to\ infiltration\ \ in\ cold\ aisle}{Total\ enthalpy\ rise\ at\ the\ racks\ exhaust\ from\ the\ CRAC\ exit}$$

The numerator denotes the Sensible Heat gained by the air in the cold aisle before entering the racks while the denominator represents the total sensible heat gain by the air leaving the rack exhausts. Since, the mass flow rates at the inlet and outlet of each rack are equal, SHI can be rewritten as a function of rack inlet, rack outlet and CRAC outlet temperatures. Thus,

$$SHI = \frac{T_{r_{in}} - T_r}{T_{r_{out}} - T_r}$$

For better performance of the air conditioning systems of the Data Centre, SHI should be as low as possible. Also, the RHI or Return Heat Index is formulated as,

$$RHI = \frac{\partial Q}{Q + \partial Q}$$

$$= \frac{Total\ Heat\ extraction\ from\ the\ Racks}{Total\ enthalpy\ rise\ at\ the\ racks\ exhaust\ from\ the\ CRAC\ exit}$$

For better performance of the air conditioning system of the Data Centre, RHI should be near to unity.

CHAPTER-4

AIRFLOW IN THE PLENUM

"DATA CENTRES" airflow distribution has a major impact on optimized cooling of data centre. In general cooling air enters a server rack through the front face and hot air exits from the rear face. In a large room, in which 2000 server racks may be spread all over the room, it is not easy to supply cooling air to each rack. Cooling air needs to enter at the foot of the server racks and then it will circulate inside the racks to servers. Means air needs to enter at the bottom and has to raise to certain height in the main room where server's racks and all other equipment will be placed. Hence the airflow distribution required special arrangements to circulate inside the Data Centres.

These are the most commonly used arrangements

- False floor (Raised floor) airflow distribution
- Overhead airflow distribution

False floor (Raised floor) airflow distribution:

The server racks are installed on a tile floor that is raised to height of 0.3–0.6 m (12–24 in.) Air-conditioners are used to pump cold air into the space below the raised floor. The floor tiles are removable and some of the solid tiles can be replaced by perforated tiles or grilles to permit the cold air to enter the above-floor space. By locating perforated tiles at the foot of the server racks, cooling air is delivered to them. The hot air then finds its way back to the air-conditioners. The raised-floor arrangement gives unlimited flexibility. If the layout of the server racks is changed, all that is needed is to rearrange the perforated tiles so that cooling air is delivered at the new locations of the server racks. Since there is no permanent ducting, no elaborate dismantling or construction is necessary.

Overhead airflow distribution:

The hot air and cold air both will send to the ducts in overhead airflow distribution. With a duct system through which supply air at different points

of the data centre and return air is also collected either through the duct situated relatively at a lower heights compared to the supply duct through the plenum created between the ceiling and false ceiling. At the opening of the supply ducts, diffuser will be attached that ensures the proper distribution of air to each corner of the data centre.
This method is not an efficient way to supply the air as that it tries to maintain the whole at the required temperature which leads to overcooling at some point. This method is inefficient also because in this arrangement the mixing of cold and hot air can be done.

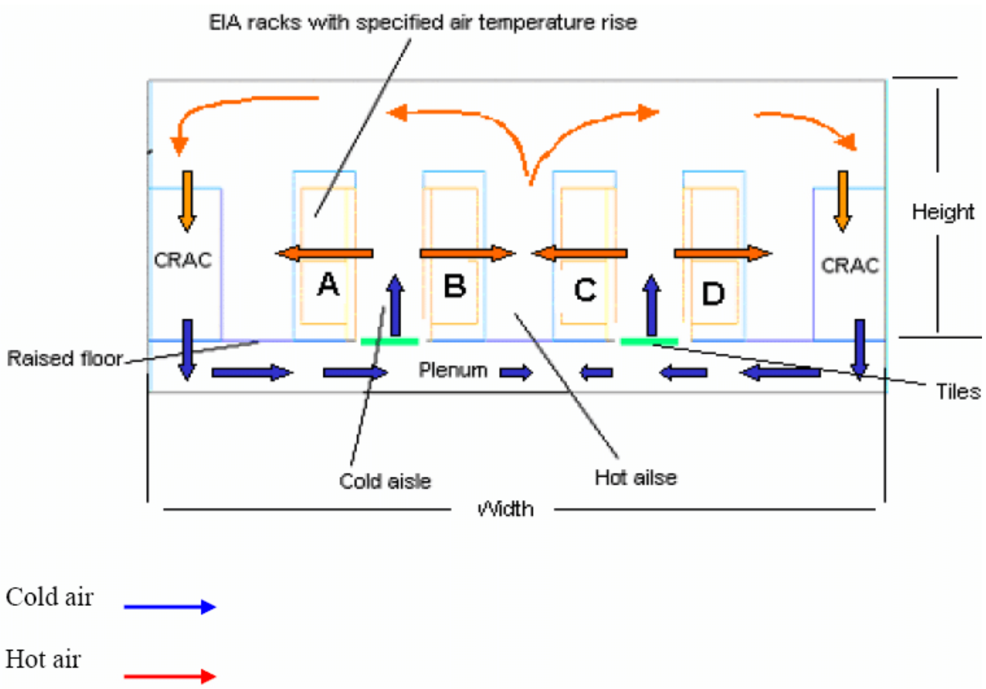


Fig :5 Raised floor Air Distribution

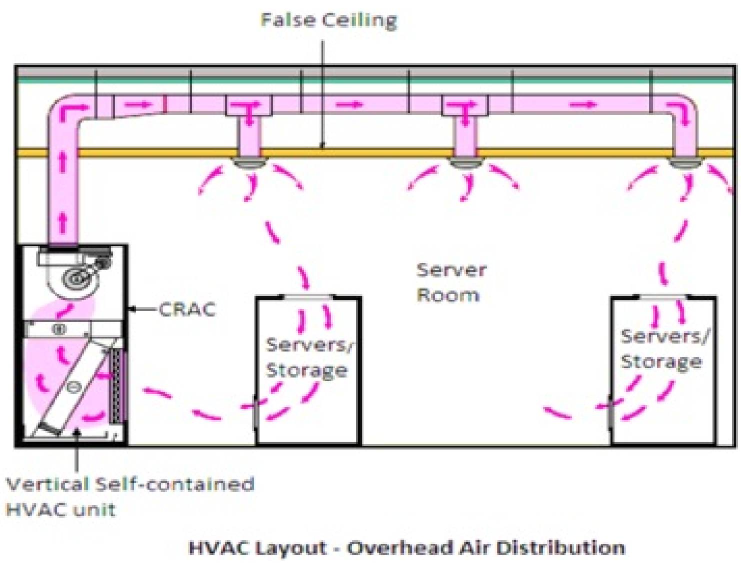


Fig :6 Overhead Air Distribution

In this thesis airflow distribution is considered through raised floor. Now the detailed discussion about the raised floor will be discussed.

As per earlier discussion the server rack gets air from the plenum through the perforated tiles but the amount of air that it can get depends on many factors. Some of them are as follows:

- Arrangement of the plenum
- Size of the plenum
- Open area of the perforated tiles
- Location of CRAC units
- Flow rate of CRAC units
- Under-floor flow restrictions like those caused by cables and pipes

By observing any thermal structure of data centre, there are only certain sections that have high heat zones and the most common solution is that why not just remove these heat by supplying excess air. In practise also apply the same concept but as has its limitations. One of the problems that arise is the heat load of each server gets change every other second so to cope up with this we need to control air flow pattern very effectively to efficiently utilize cooling air more efficiently.

Even though it is not easy to control air flow patterns in the data centre but there are

A few parameters through which airflow pattern in the data centre can be controlled.

Following are some of them:

- Change the plenum height.
- Provide varying open areas to perforated tiles
- Re-locate the CRAC units
- Relocate the perforated tiles
- Install some flow obstructions in the plenum

Floor of tiles also need to ensure certain things. Some of it is as follows:

It must be designed in such a way that it can bear the weight of the server, server rack, CRAC. Other data centre equipment. Only a cabinet full of servers can weigh up to 3000lbs.

- We need to ensure that it is constructed in accordance with the guidelines of the governing body.
- Floor materials should be able to resist wear of it
- Floor material should be able to resist abrasion.
- Floor should also contain conductive material which can remove and stop the accumulation of harmful static electricity from the environment.

Need of supplying sufficient flow of air to each of the server rack:-

Each of the server racks has its own fan which draws in a known amount of chilled air. Each rack has a predefined maximum inlet temperature which should not be breached, if inlet temperature goes beyond that point over heating of the rack will start happening which wiII leads to the malfunctioning of equipment. Equipment failure is not a big issue in comparison to financial losses the company has to bear when such failure of equipment takes place in the data centre.

Figures 7 and 8 illustrate the airflow with simplified examples. In both cases, each rack dissipates 2 kW of heat and requires an airflow rate of 0.15 m^3/ s. In Fig. 7, the airflow supplied at the perforated tile is indeed 0.15 ^{3}. This meets the demand of the server rack. The cold air is supplied at 12.8 °C, it heats up to 24 °C, and this hot air returns to the CRAC unit. Since the temperature entering the rack is 12.8 °C, which is well below the acceptable inlet temperature, proper cooling is assured.

It is not always possible to control the amount of airflow emerging from each perforated tile. Figure 8 shows the case in which insufficient airflow is supplied from the perforated tile. Whereas the rack requires 0.15 m^3/ s, the perforated tile supplies only half that amount. This reduced flow is sufficient to cool the bottom half of the rack. The cooling airflow needed by the top half is now taken from the hot air returning to the CRAC unit. This air has resulted from the mixing of the exhaust air at 24°C from the bottom half of the rack with the much hotter air emerging from the top half of the rack. The result is that the maximum inlet temperature to the rack is 35 °C, which may be unacceptable for many electronics designs. (The idealized picture in Fig. 8 assumes that the exhausts of the top and bottom halves of the rack are well mixed to the temperature of

35 °C. In reality, if such perfect mixing does not take place, even hotter air is likely to enter the inlet of the top half of the rack.)

These simple examples lead to a very important conclusion. The key to good cooling is to supply the required amount of cold airflow at the foot of each server rack. If this is done, satisfactory cooling is assured. If this cannot be done, cooling difficulties arise and then they are usually very hard to overcome.

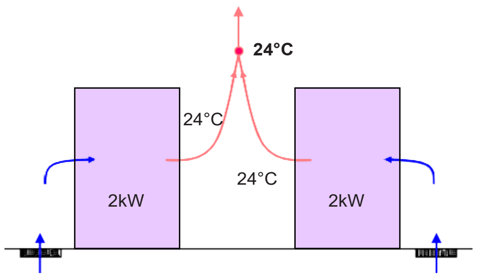


Fig:7 Required airflow supplied

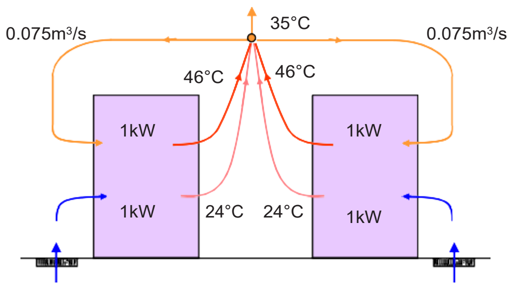


Fig :8 Insufficient airflow

CHAPTER-5

SIMULATION AND RESULTS

Introduction:

Data centre air conditioning design depends on air flow distribution in the room. Designing without knowing the air flow distribution is like a trial and error process. It consumes time, labour and also expensive. Simulation process is used to find the air flow distribution. Therefore, Computational Fluid Dynamics (CFD) is used to find the simulation process in the data centre. CFD technique shows attractive Visualization that we can easily understand and find out Hotspots in the data centre. With CFD process we can reduce the time and labour and also reduce expenditure. Hence, CFD techniques are widely used in defining the air flow distribution in a data centre.

Method and Governing equations:

Air flow in a data centre considered as a turbulent flow. Also CFD and turbulence model will gives better simulation results. Fluent is used as a tool for the simulation. So **K – ε** turbulent model and standard wall function is considered for analyzing the simulation process. Pressure –Velocity coupled with SIMPLE algorithm. As per ref [1] **K – ε** equation is mentioned below.

Where **k** equation is

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k$$

And **ε** equation is

$$\frac{\partial(\rho \epsilon)}{\partial t} + \frac{\partial(\rho \epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_1 \frac{\epsilon}{k}(G_k + C_3 G_b) - C_2 \rho \frac{\varepsilon^2}{k} + S_\varepsilon$$

Where ε is defined as,

$$\varepsilon = \frac{\mu}{\rho}\overline{\left(\frac{\partial u_i^{/}}{\partial x}\right)\left(\frac{\partial u_i^{/}}{\partial x}\right)}$$

and the turbulent viscosity is expressed as

$$\mu_t = \rho\, C_\mu \frac{k^2}{\epsilon}$$

Where G_k is turbulent kinetic energy product; G_b is turbulent kinetic energy caused by buoyancy; Y_M is the influence of fluctuating expansion of compressible turbulence on total dissipation rate; S_k and S_ε are source terms depending on the conditions; C_i (i = 1,2,3) is an empirical constant.

SIMULATION FOR TWO DATA CENTRES:

Two Data Centres are considered for simulation. These two are located in Swasthya Bhawan ,GN-29 Sector-V, Salt Lake, Street Number 2, Kolkata, West Bengal – 700091. Out of the two Data Centres case study-1 is performed on old design and case study-2 performed on modified design. Design, airflow rate and heat generation from server racks these data are collected from the Officials of Swasthya Bhavan.

CASE STUDY- 1 OLD DESIGN

1) Design

For case study-1 is performed on Design 1 as shown in fig 9.

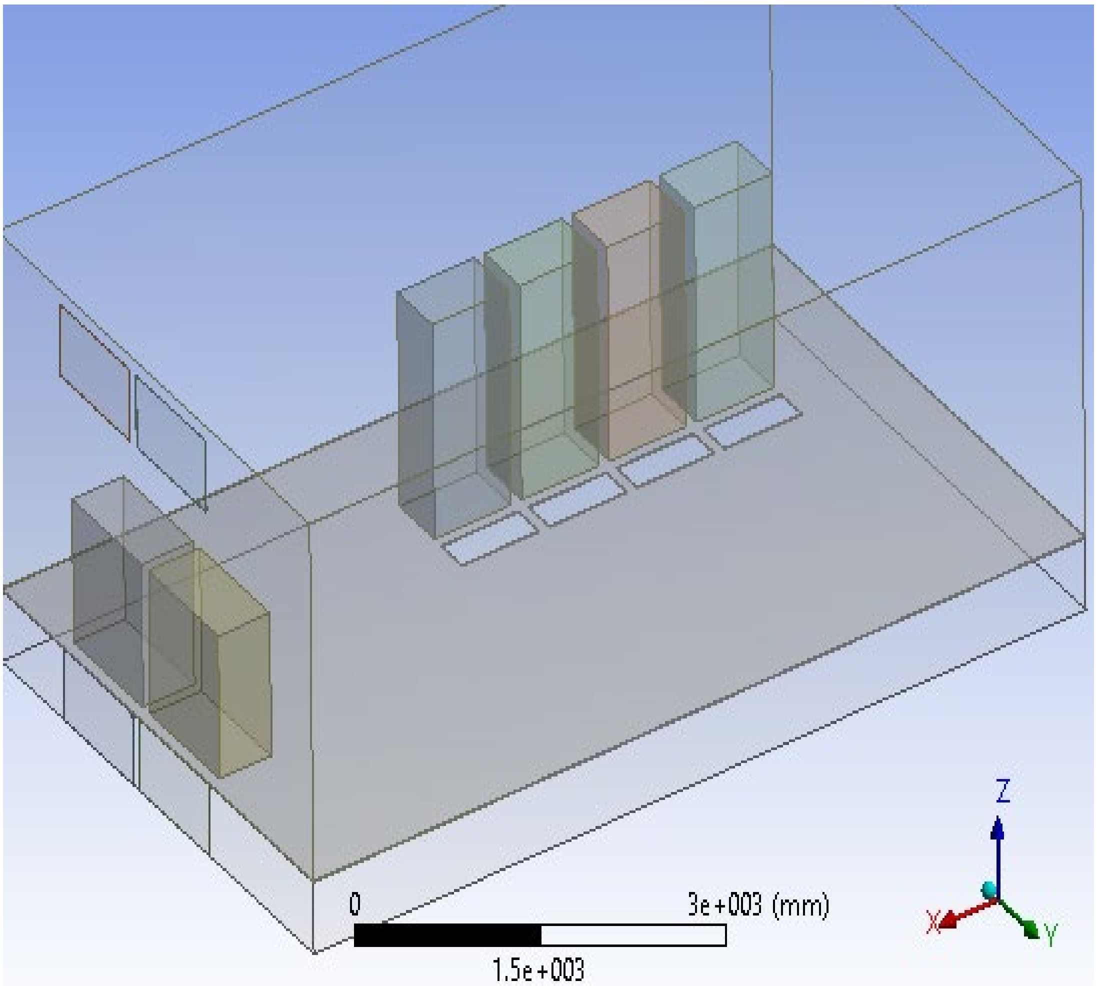


Fig : 9; 3D Design of server room of Health Bhavan

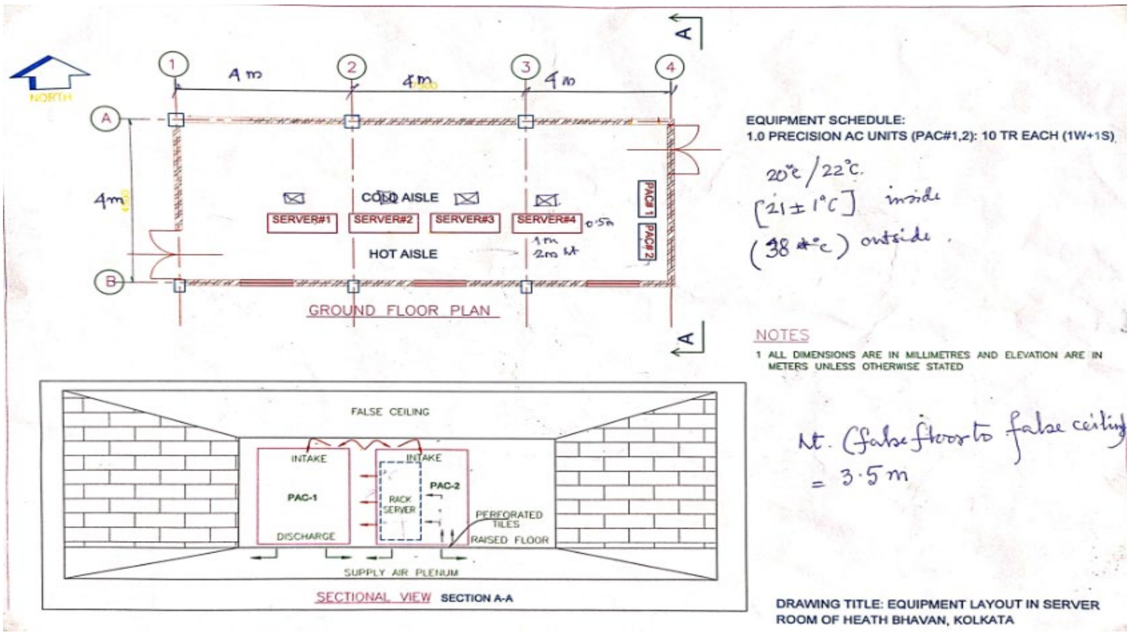


Fig :10 Layout of server room of Health Bhavan

From the fig 9, the server room consists of Main room, Raised floor, four server racks and two CRAC. Main Room size is considered as 7500 x 4500 x 2500 mm^3. Raised floor room which is below the main room the size is considered as 7500 x 4500 x 500 mm^3. Two CRAC are provided inside the room. In which one will be used and other will be standby purpose. Each CRAC size considered as 1000 x 500 x 1000 mm^3. Two cold air inlets are provided on one side of the raised floor. Each inlet size is 1000 x 500 mm^2. Two hot air outlets are provided on the one side of main room at a distance of 100 mm from the main room ceiling. Each outlet size is 1000 x 500 mm^2

Four servers are placed inside the main room. Server which is near to the inlets and outlets is noted as server -4 and next servers are 3,2 and 1 respectively. Each server rack is size of 750 x 500 x 1500 mm^3 is considered. In front of the each server rack vents are provided for entering the cold air from the raised floor. Each vent is provided with a size of 750 x 300 mm^2. Both inlets and outlets are considered on the same side. Table 2 indicates the sizes of all the parts of hospital server room.

S.no	Name	Size	Units	Quantity
1	Main Room	7500 x 4500 x 2500	mm^3	1
2	Raised Floor	7500 x 4500 x 500	mm^3	1
3	Servers	750 x 500 x 1500	mm^3	4
4	CRAC	1000 x 500 x 1000	mm^3	2
5	Vents	750 x 100	mm^2	4
6	Inlets	1000 x 500	mm^2	2
7	Outlets	1000 x 500	mm^2	2

Table : 2

2) Meshing :

Meshing is carried on all the parts of the server room.

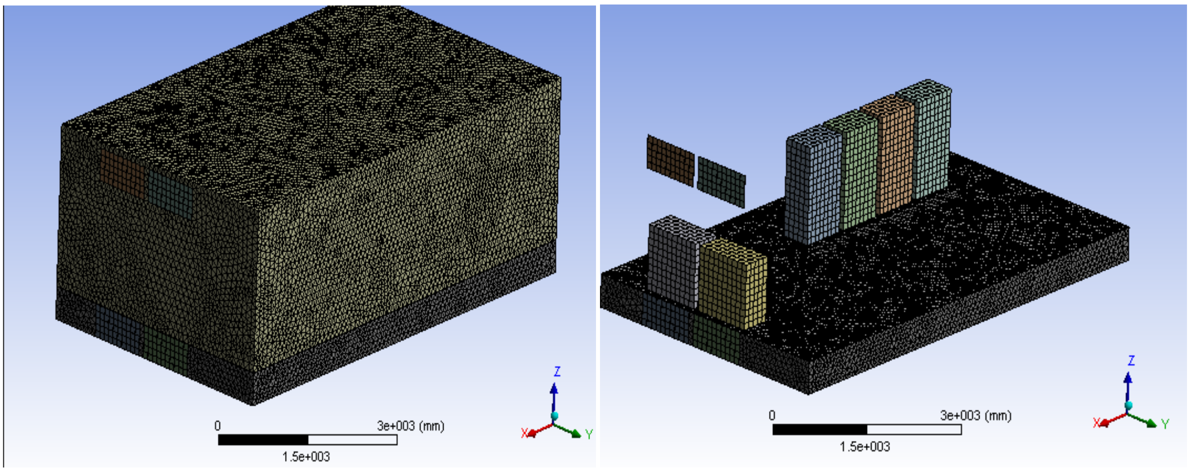


Fig :11 Meshing of server room of Health Bhavan

Fig 11 indicates meshing of all parts of the design. Total nodes and elements are 158801 and 881850 respectively.

3) Experimental Setup & Solution:

Turbulent flow K – ε model with standard wall function is considered . Main room and Raised /False floor of data centre are considered as fluid zone. All four servers and CRACs are considered as solid zone. For each server heat generation is considered as 3 kW/m^3. Out of two CRACs one will be used. So for the two Velocity Inlets, only inlet-1 velocity is considered as 4.5 m/s. Inlet-2 velocity is considered as zero. Also for Inlet-1 temperature is considered as 20^0 C and inlet-2 is kept constant. Two Pressure outlets are considered with constant values. Pressure – Velocity coupled with SIMPLE method. Table 3 indicates all boundary conditions and heat generation source of servers.

S.no	Name	Values	Units
1	Inlet air velocity -1	4.5	m/sec
2	Inlet air velocity -2	-	-
3	Inlet air Temperature -1	20^o	Celsius
4	Inlet air Temperature -2	-	-
5	Heat generation in Server 1	3000	Watts/m^3
6	Heat generation in Server 2	3000	Watts/m^3
7	Heat generation in Server 3	3000	Watts/m^3
8	Heat generation in Server 4	3000	Watts/m^3
9	Outlet air Pressure &Temperature	Kept as per the fluent	Kept as per the fluent

Table : 3

Figures 12 to 16 shows the boundary conditions in the fluent.

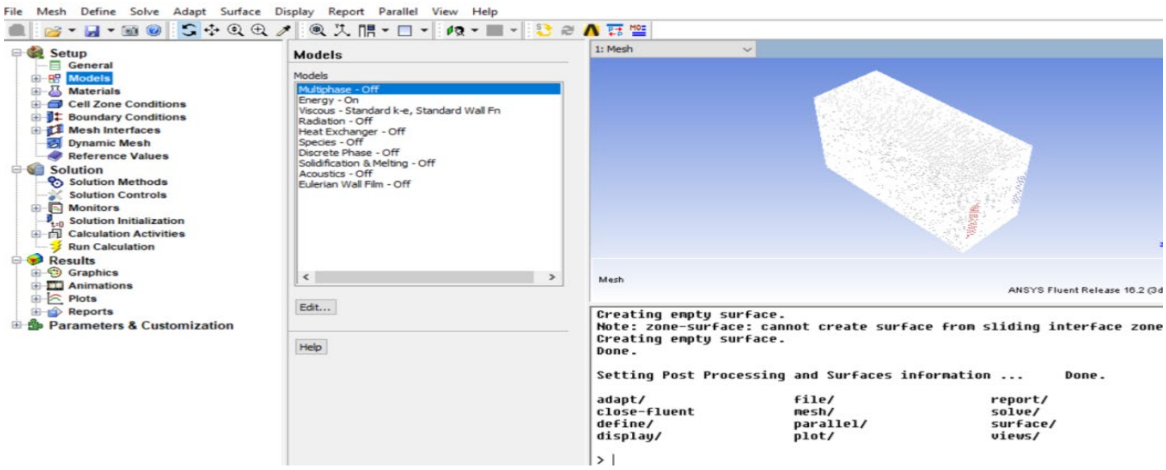


Fig:12

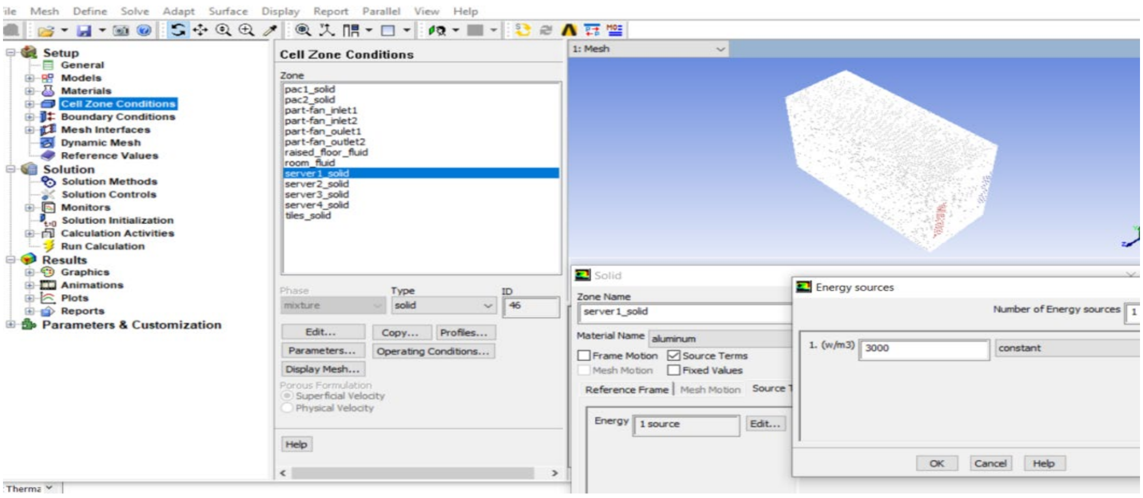


Fig : 13

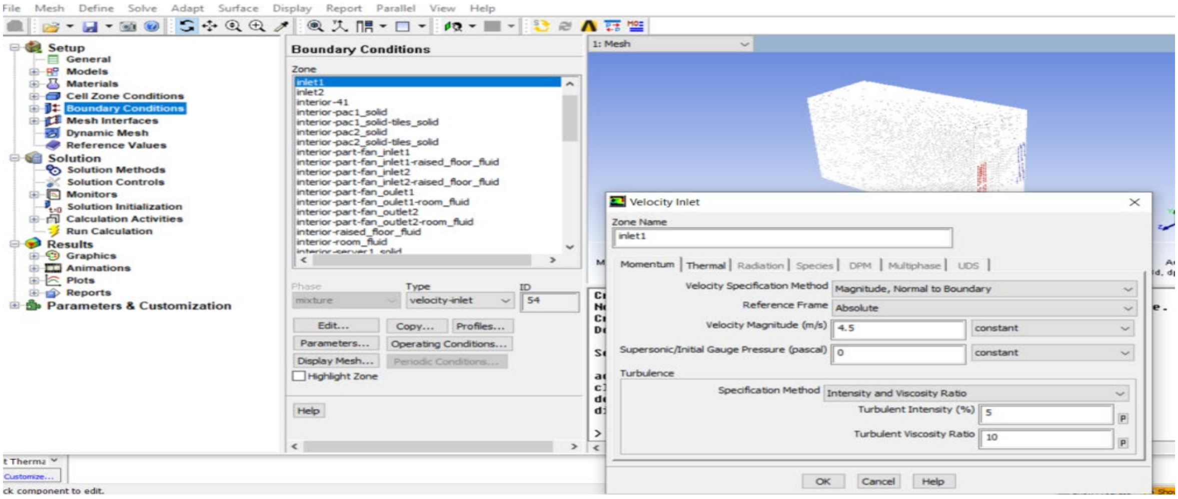

Boundary Conditions
Velocity Inlet
Zone Name
inlet1
Velocity Specification Method
Magnitude, Normal to Boundary
Reference Frame
Absolute
Velocity Magnitude (m/s)
4.5
Supersonic/Initial Gauge Pressure (pascal)
0
Turbulence
Specification Method
Intensity and Viscosity Ratio
Turbulent Intensity (%)
5
Turbulent Viscosity Ratio
10

Fig : 14

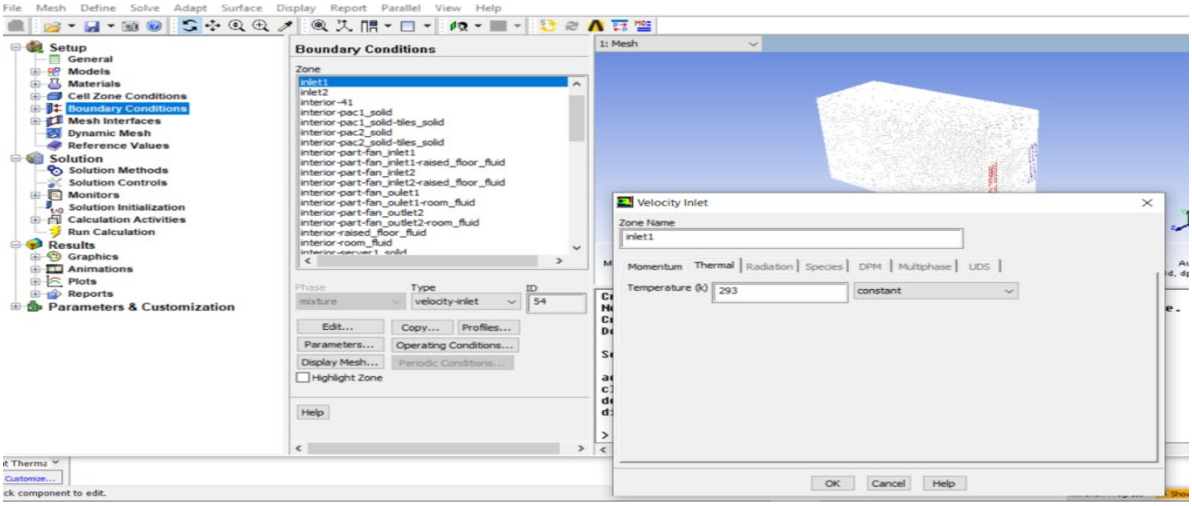

Boundary Conditions
Velocity Inlet
Zone Name
inlet1
Temperature (k)
293
constant

Fig :15

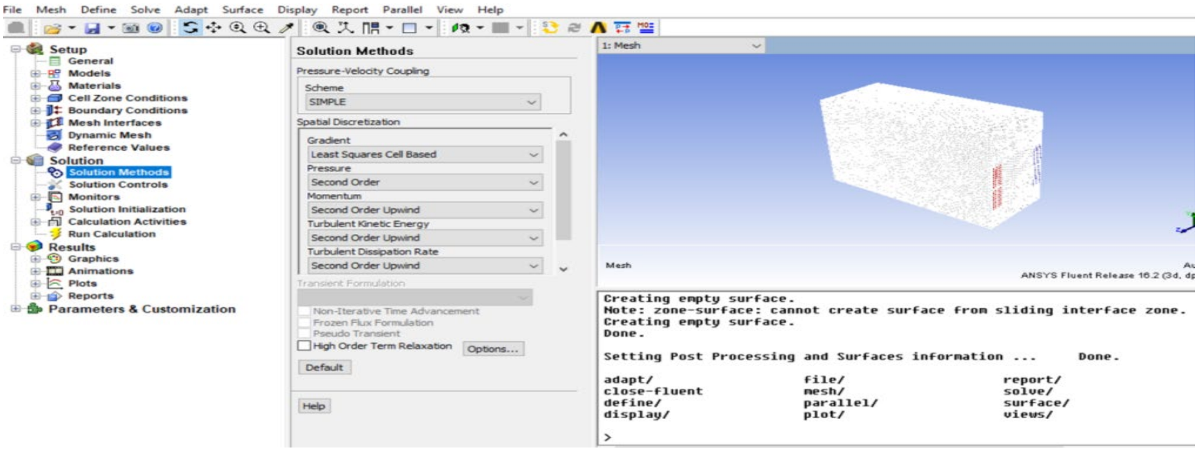


Fig :16

4) Result & Discussion:

i) Temperature contour:

Fig 17 shows temperature contours of all servers.

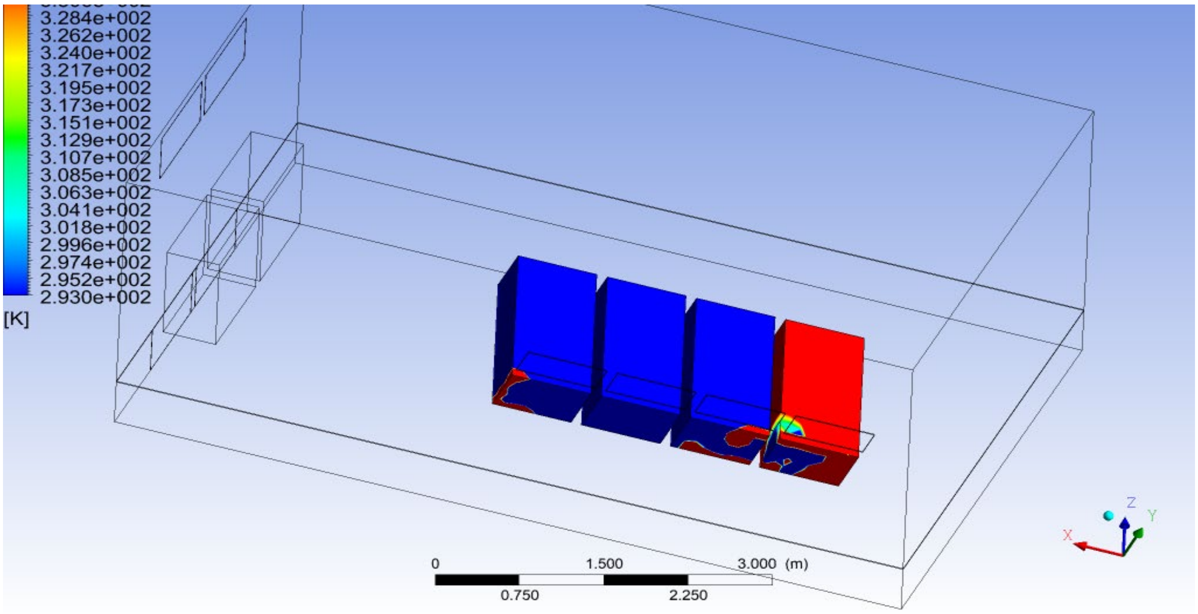


Fig :17

Out of four servers server 1 which is far away to the CRACs is found with more hotspots. Then server 3 and server 1 have more hotspots respectively. Server 2 is the efficiently cooled compared with all other servers.

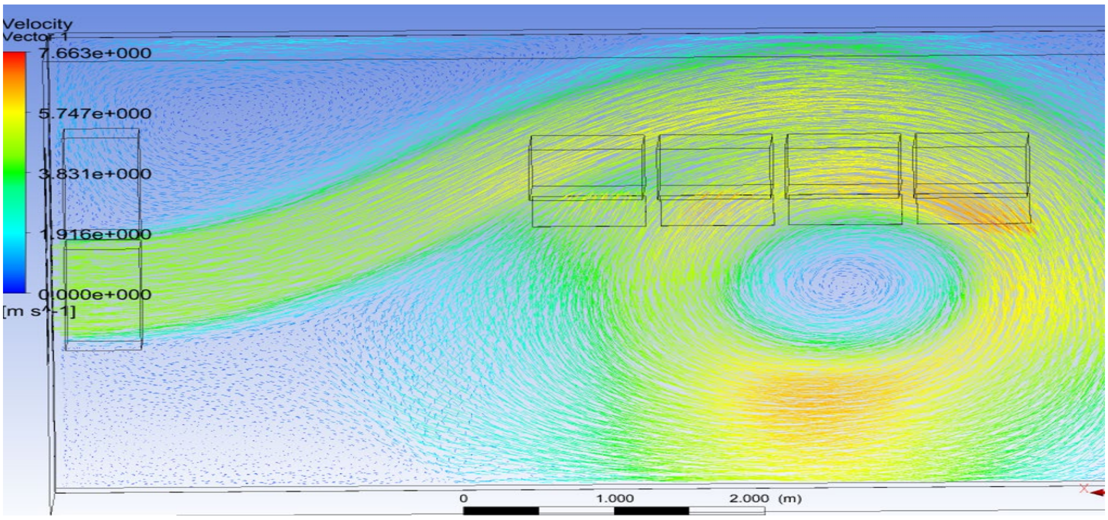


Fig :18

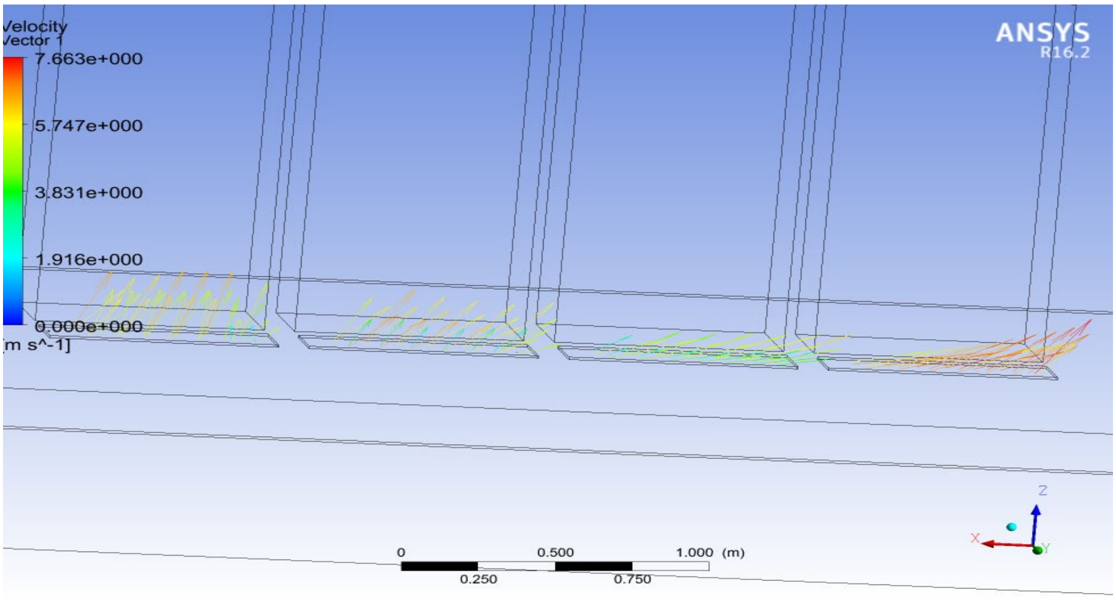


Fig :19

From fig 18 and 19 are represent the velocity vectors in the raised floor and at the vents. From fig 18 anyone can clearly identify that the cold air coming from the inlet-1 is moving towards to the servers and then hitting the walls of the room and making a **swirl type** of flow. After making a swirl action the air will enters through the vents that will be visualize in fig 19.

From fig 19 the arrow marks of the velocity vectors are clearly visualize. In vent 4 which is in front of server-4 velocity vectors are clearly vertically upward direction and for vent- 3 which is in front of server – 3 also vertically upward direction with some inclinement.

Whereas in vent-2 and especially in vent-1 which is in front of server-1 the velocity vectors are moving away from the server sides. This will clearly visualize in fig 20.

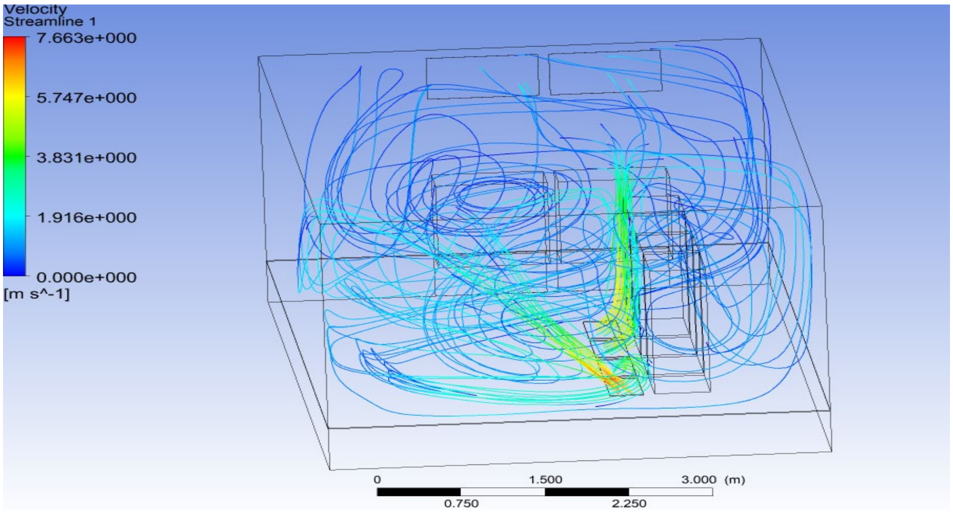


Fig :20

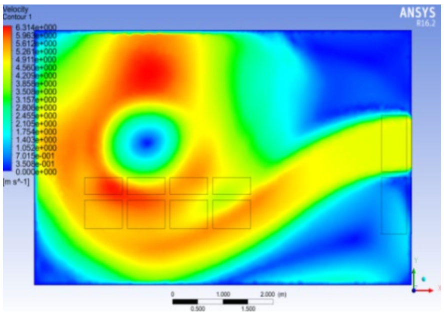
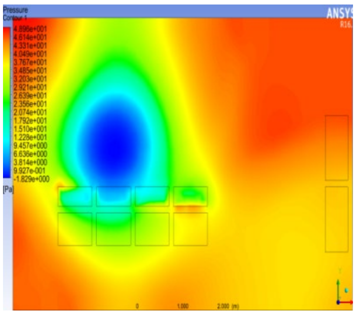
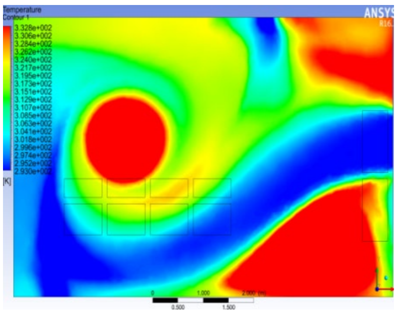




Fig :21 Fig : 22 Fig : 23

Also from figures 21, 22 and 23 which represents velocity, pressure and temperature contours in raised floor. From these figures also can visualize that there is lack of cooled air supply in front of the server-1 and server-2.

The reason behind the server-1 will have more hotspots compared to others is clearly due to swirling action of the cooled air. Because of the swirling from fig 11 & 12 the velocity vector in front of the server-4 and server-3 are moving towards to them. Whereas velocity vector in front of the server-2 and server-1 are moving away from them.

ii) Velocity Vectors:

Fig 18 represents velocity vector in raised floor. Already discussed that velocity vector in raised floor will form a swirl type of action. Because of the heat generating sources the cold air will attracted towards the servers.

Fig 19 shows velocity vector at vents. Again because of the swirl action the velocity vector at vents are towards the server side at vent 3 and 4 and away from the server side at vents 1 and 2.

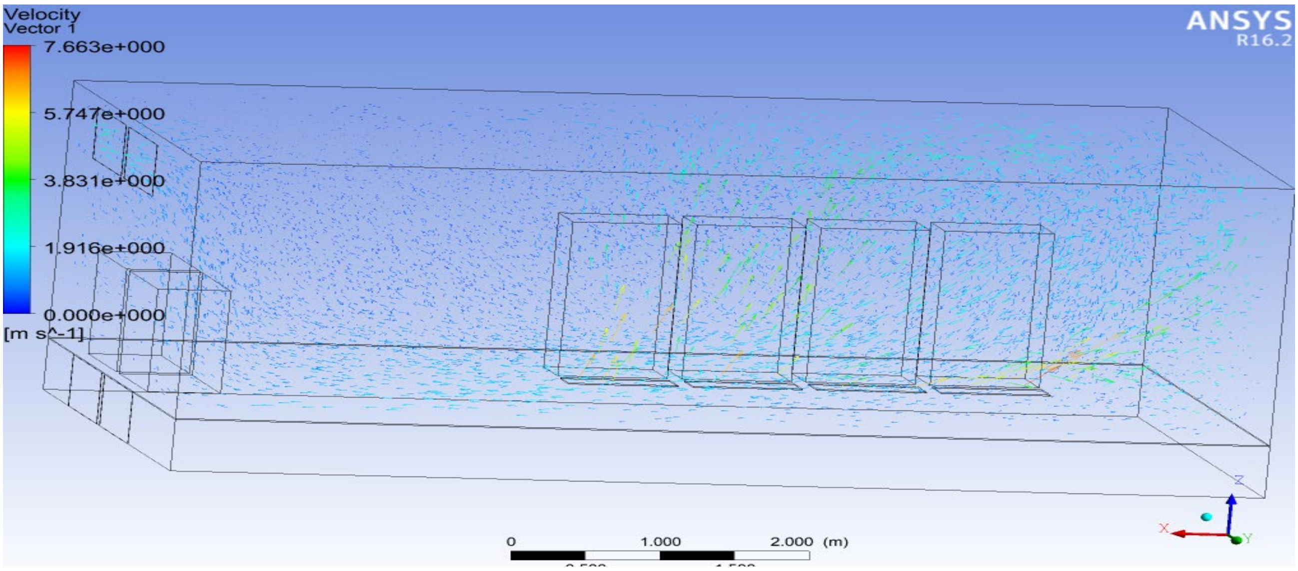


Fig :24

Fig 24 represents the velocity vector inside the room. From the fig can visualize that velocity vector at vents having higher velocity compared to the reaming vectors spread in the room.

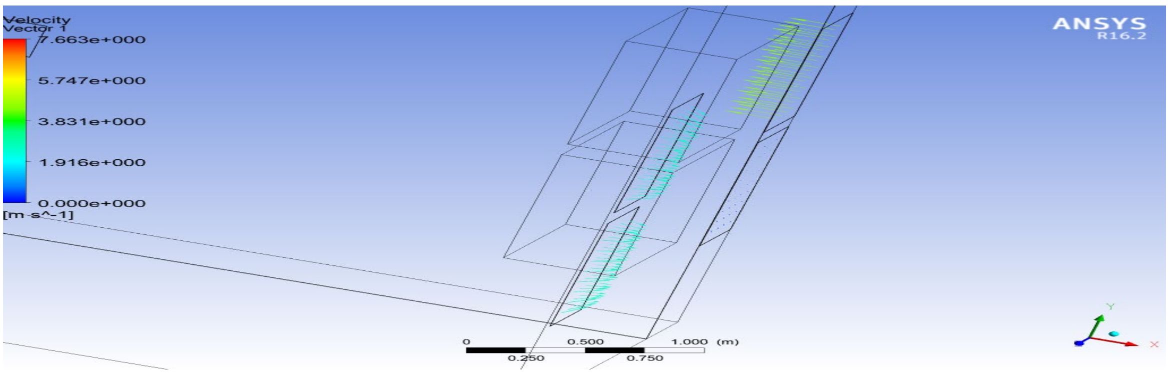


Fig :25

Fig 25 shows that velocity vectors at inlets and outlets. At inlet 1 can identify the velocity entering into the server which is the input given in the fluent i.e 4.5 m/s. whereas at inlet-2 there is zero velocity because of standby of CRAC-2. At outlets velocity coming out of them can clearly visualize with arrow marks.

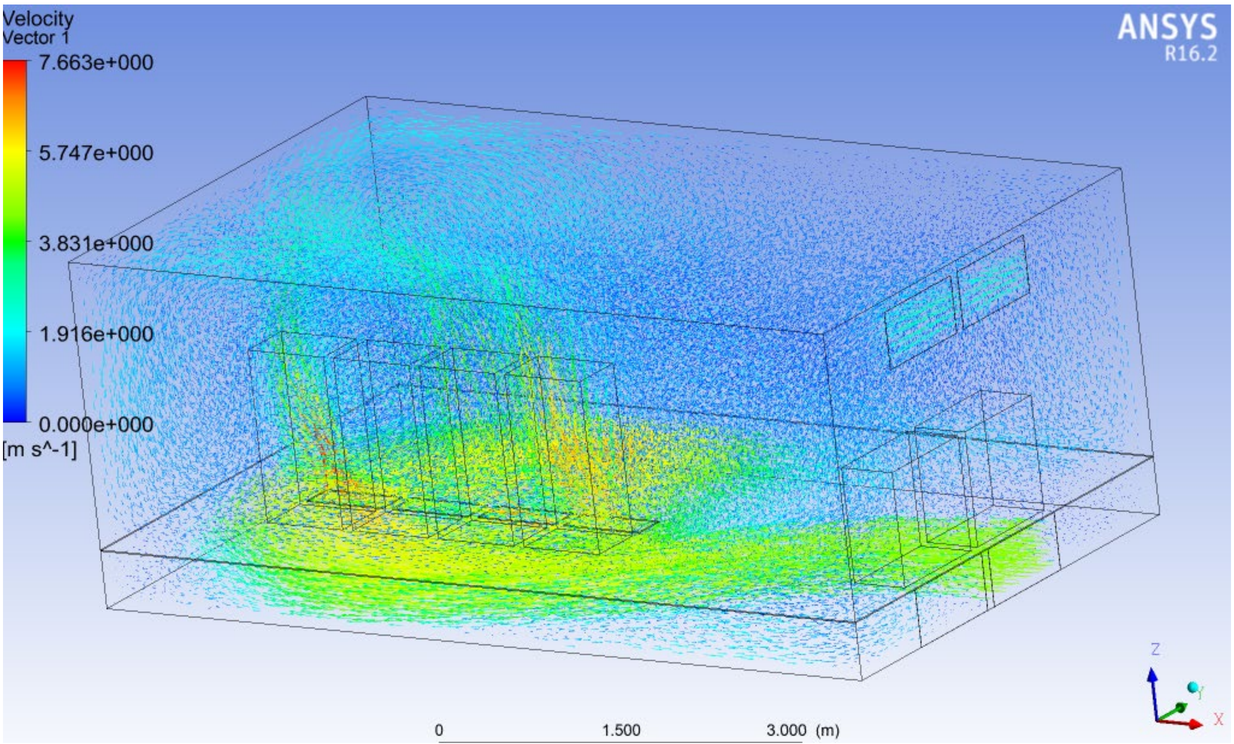


Fig :26

Fig 26 shows velocity vector of entire data centre. Here can anyone easily identify the different velocities at different locations. At inlet the input velocity will be increased at the vents and again decreased inside the room finally coming out of the outlets increased again.

iii) <u>Velocity streamline :</u>

Fig 20 shows the velocity streamlines at vents. The velocity streamlines coming out of the vents are having the highest velocity compared to all other locations. Because vents are actually acting like as a nozzles. Automatically nozzle increases the velocity. But already discussed about swirling action that formed in the raised floor velocity streamlines at vents 1 and 2 moving away from the server side and at vents 3 and 4 moving towards the server sides.

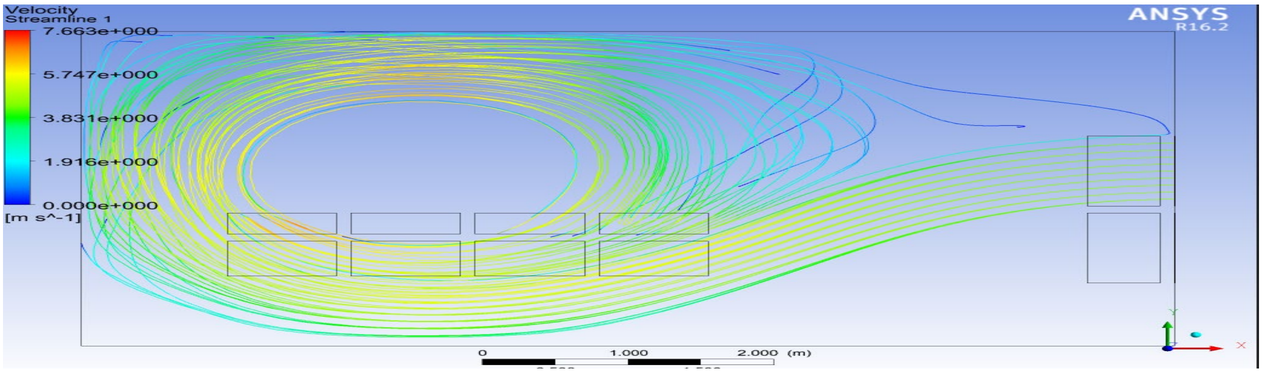


Fig :27

Fig 27 shows the velocity streamlines at inlet-1. Inlet-1 velocity input given as 4.5 m/s and after entering into the raised floor it forms swirling motion and then enters to the room through the vents.

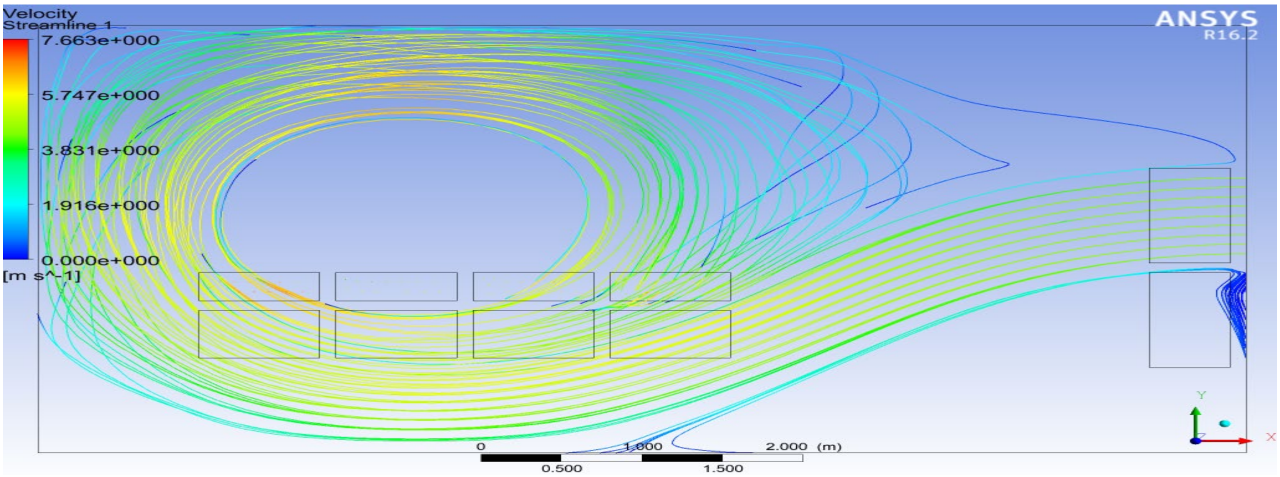


Fig :28

Fig 28 shows the velocity streamlines in raised floor. Here there is no velocity streamline from the inlet-2 as it is idle.

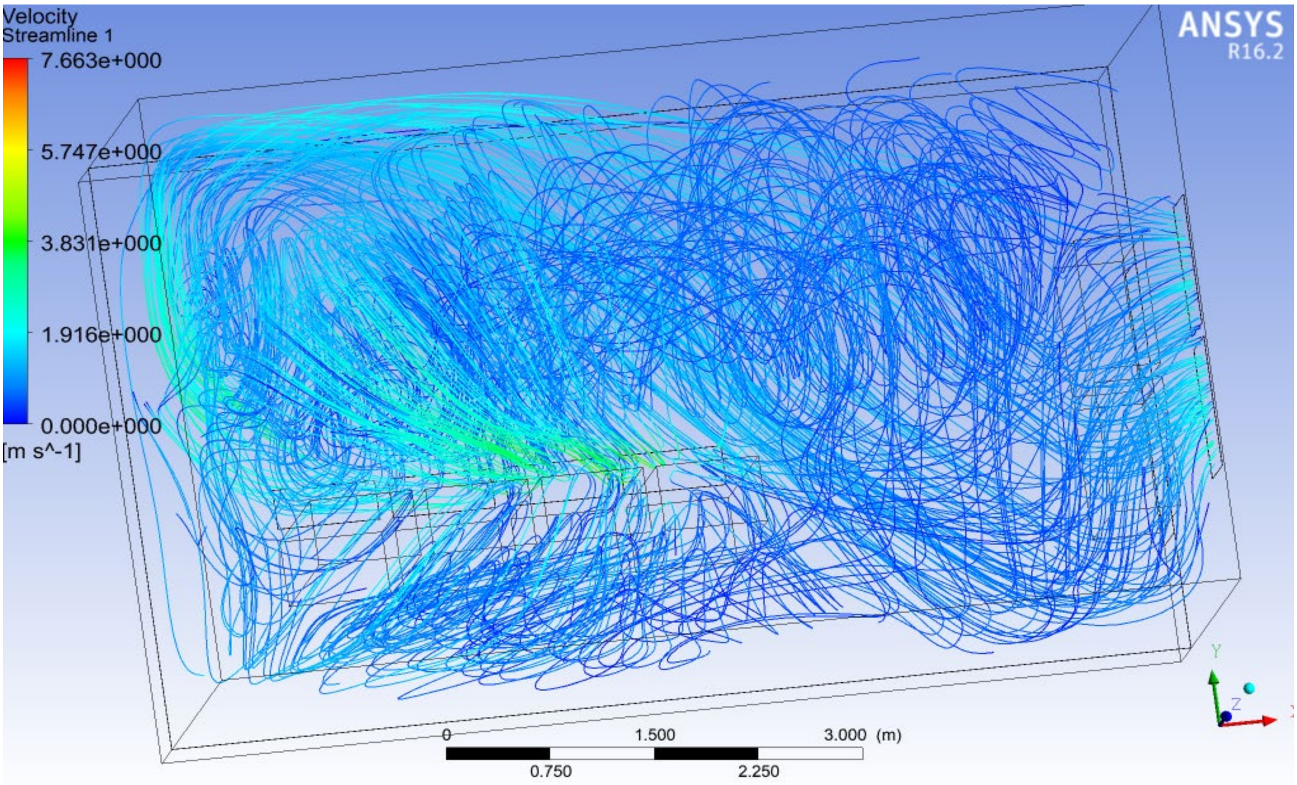
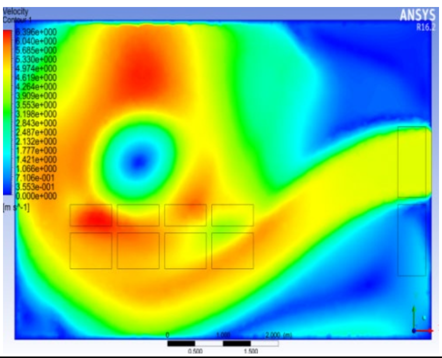
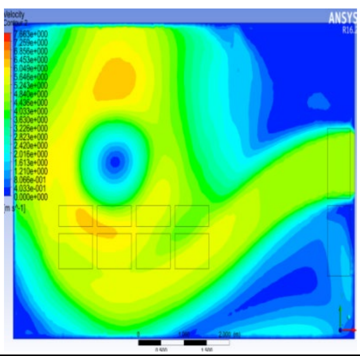


Fig :29

Fig 29 shows the velocity streamlines in the room. The velocity streamline coming from the vents which having higher velocity and then circulating the entire room the velocity decreases. From the fig can anyone visualize that the velocity streamlines are hitting the room walls and recirculation in the entire room. Because of this the velocity decreases and when it is coming out of the outlets velocity increases.

iv) <u>Contours of Velocity, Pressure and Temperature at different locations in XY-plane :</u>





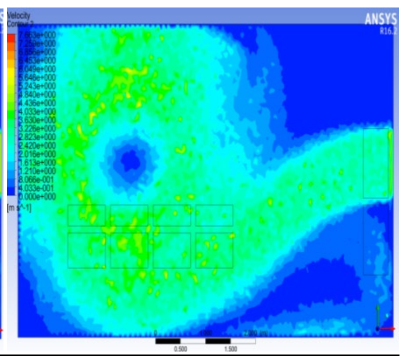


Fig :30; XY@ -150 mm Fig : 31; XY@ -300 mm Fig : 32; XY@ -450 mm

Fig 30, 31 and 32 are velocity contours at -150 mm, -300 mm and -450 mm respectively from the XY plane. These planes all are considered in the raised floor. From the figs observe that as the depth of raised floor increases from XY-axis, velocity is decreasing.

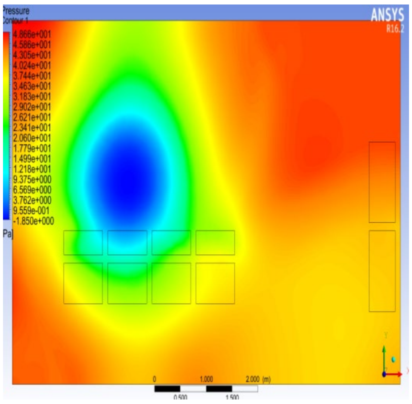


Fig :33; XY@ -150 mm

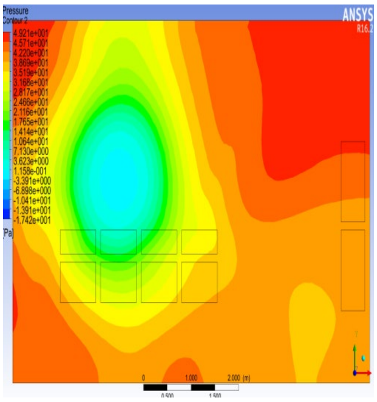


Fig : 34; XY@ -300 mm

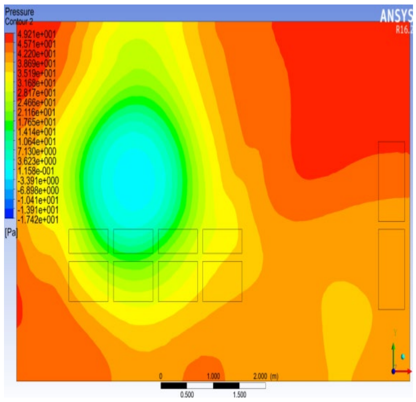


Fig : 35; XY@ -450 mm

Fig 33, 34 and 35 are pressure contours at -150 mm, -300 mm and -450 mm respectively from the XY plane. These planes are also considered in the raised floor. From the figs observe that as the depth of raised floor increases from XY-axis, pressure is increasing.

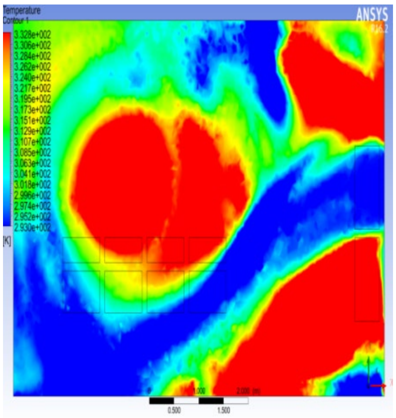


Fig :36; XY@ -150 mm

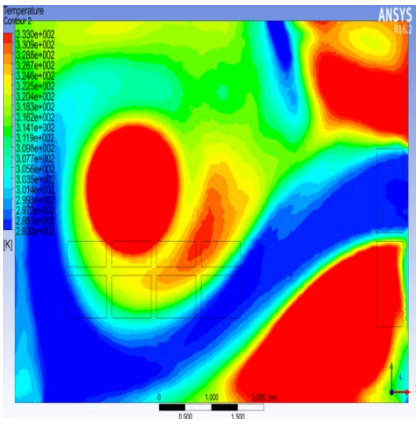


Fig : 37; XY@ -300 mm

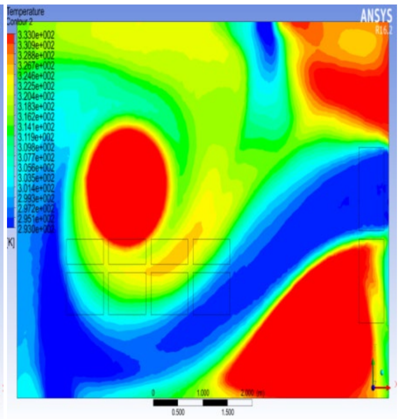
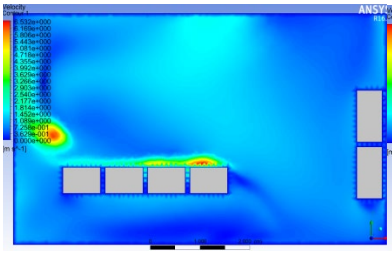
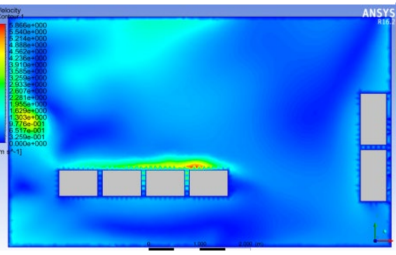


Fig : 38; XY@ -450 mm

Fig 36, 37 and 38 are temperature contours at -150 mm, -300 mm and -450 mm respectively from the XY plane. These planes are also considered in the raised floor. From the figs observe that as the depth of raised floor increases from XY-axis, hotspots are decreases.





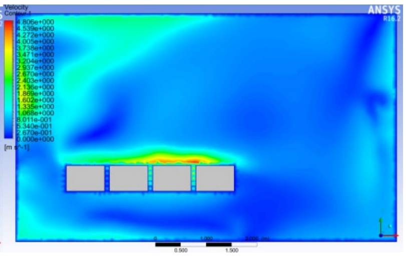
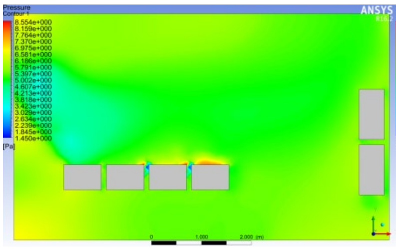
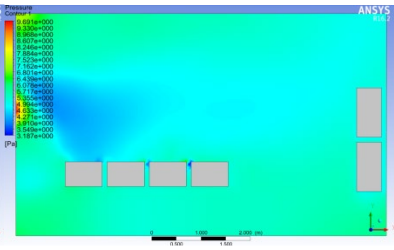


Fig :39; XY@ 500 mm Fig :40; XY@ 1000 mm Fig :41; XY@ 1500 mm

Fig 39, 40 and 41 are velocity contours at 500 mm, 1000 mm and 1500 mm respectively from the XY plane. These planes all are considered in the room. From the figs observe that as the height of room increases from XY-axis, velocity is decreasing.





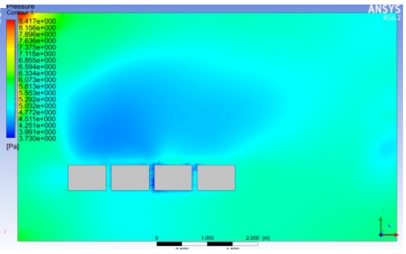
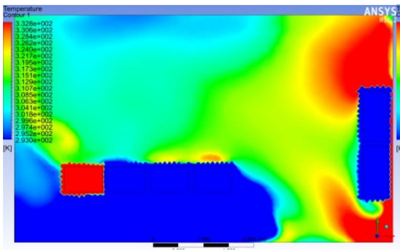
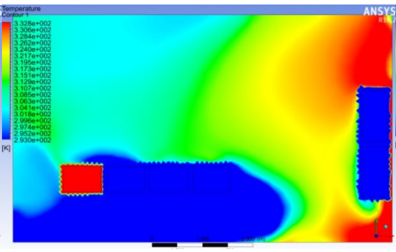


Fig :42; XY@ 500 mm Fig :43; XY@ 1000 mm Fig :44; XY@ 1500 mm

Fig 42, 43 and 44 are pressure contours at 500 mm, 1000 mm and 1500 mm respectively from the XY plane. These planes all are considered in the room. From the figs observe that as the height of room increases from XY-axis, pressure is decreasing.





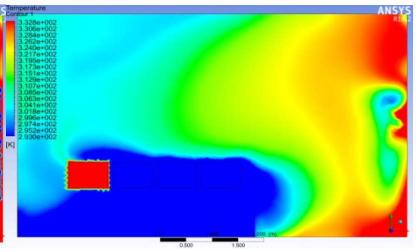


Fig :45; XY@ 500 mm Fig :46; XY@ 1000 mm Fig :47; XY@ 1500 mm

Fig 45, 46 and 47 are temperature contours at 500 mm, 1000 mm and 1500 mm respectively from the XY plane. These planes all are considered in the room. From the figs observe that as the height of room increases from XY-axis, hotspots are decreasing.

CASE STUDY-2 MODIFIED DESIGN

1) Design:

For case study-2 is performed on Design 2 as shown in fig 48

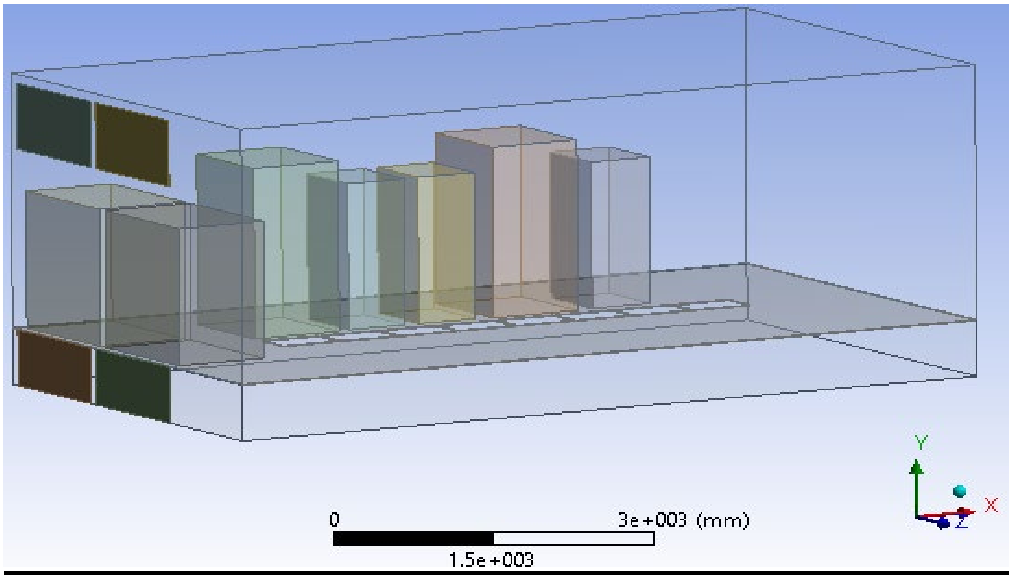


Fig : 48

S.no	Name	Size	Units	Quantity
1	Main Room	7950 x 4300 x 2790	mm^3	1
2	Raised Floor	7950 x 4300 x 610	mm^3	1
3	Big Servers	1067 x 915 x 1867	mm^3	2
4	Small Servers	762 x 610 x 1600	mm^3	3
5	CRAC	1000 x 500 x 1000	mm^3	2
6	Vents	610 x 300	mm^2	8
7	Inlets	1000 x 500	mm^2	2
8	Outlets	1000 x 500	mm^2	2

Table : 4

From the fig 48, the server room consists of Main room, Raised floor, five server racks and two CRAC. Main Room size is considered as 7950 x 4300 x 2790 mm^3. Raised floor room which is below the main room the size is considered as 7950 x 4300 x 610 mm^3. Two CRAC are provided inside the room. Each CRAC size considered as 1375 x 920 x 1500 mm^3. In which one will be used and other will be standby purpose. Two cold air inlets are provided on one side of the raised floor. Each inlet size is 1375 x 610 mm^2. Two hot air outlets are provided on the one side of main room at a distance of 100 mm from the main room ceiling. Each outlet size is 1000 x 500 mm^2. Both inlets and outlets are considered on the same side.

Five servers are placed inside the main room. Two are big servers and three are small servers. Server which is near to the inlets and outlets is noted as server -5 and next servers are 4,3,2 and 1 respectively. Each big server rack is size of 1067 x 915 x 1867 mm^3 and small servers rack is size is 762 x 610 x 1600 mm^3 considered. In front of the each server rack 8 vents are provided for entering the cold air from the raised floor. Each vent is provided with a size of 610 x 300 mm^2. Table 4 indicates the sizes of all the parts of hospital server room.

2) **Meshing :**

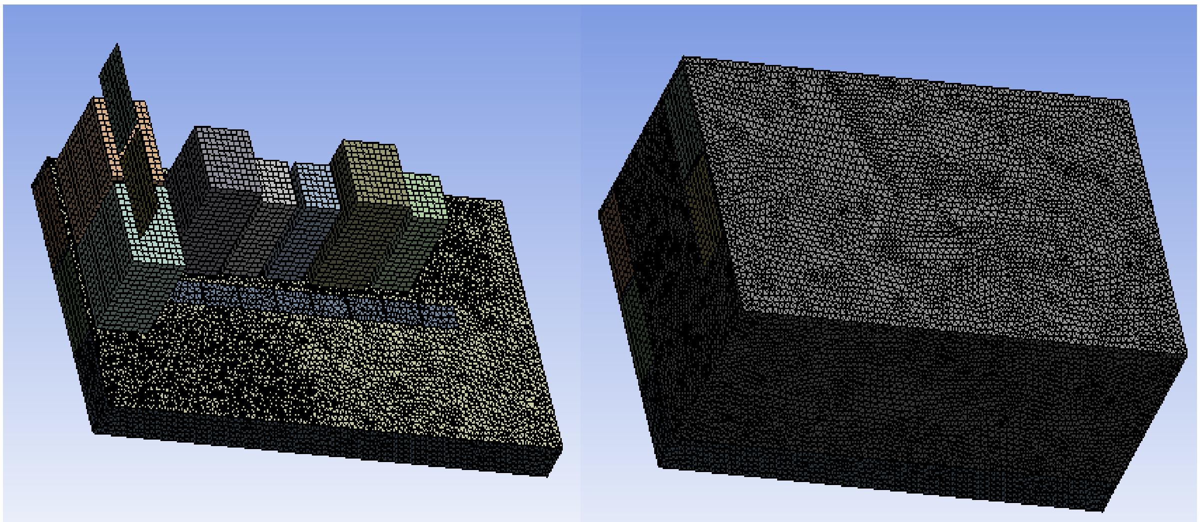


Fig : 49

Fig 49 indicates meshing of all parts of the design. Total nodes and elements are 179263 and 965483 respectively.

3) Experimental Setup & Solution:

Turbulent flow K – ε model with standard wall function is considered . Main room and Raised /False floor of data centre are considered as fluid zone. All five servers and two CRACs are considered as solid zone. There are two big servers and three small servers are there. For each bigger server heat generation is considered as 3 kW/m^3. For each smaller server heat generation is considered as 2 kW/m^3. Out of two CRACs one will be used. So for the two Velocity Inlets, only inlet-1 velocity is considered as 4.5m/s. Inlet- 2 velocity is considered as zero. Also for Inlet-1 temperature is considered as 20^0 C and inlet-2 is kept constant. Two Pressure outlets are considered with constant values. Pressure – Velocity coupled with SIMPLE method. Table 2 indicates all boundary conditions and heat generation source of servers.

S.no	**Name**	**Values**	**Units**
1	Inlet air velocity -1	4.5	m/sec
2	Inlet air velocity -2	-	-
3	Inlet air Temperature -1	20^o	Celsius
4	Inlet air Temperature -2	-	-
5	Heat generation in Server 1	2000	$Watts/m^3$
6	Heat generation in Server 2	3000	$Watts/m^3$
7	Heat generation in Server 3	2000	$Watts/m^3$
8	Heat generation in Server 4	2000	$Watts/m^3$
9	Heat generation in Server 5	3000	$Watts/m^3$
10	Outlet air Pressure &Temperature	Kept as per the fluent	Kept as per the fluent

Table : 5

Figures 50 to 53 shows the boundary conditions in the fluent.

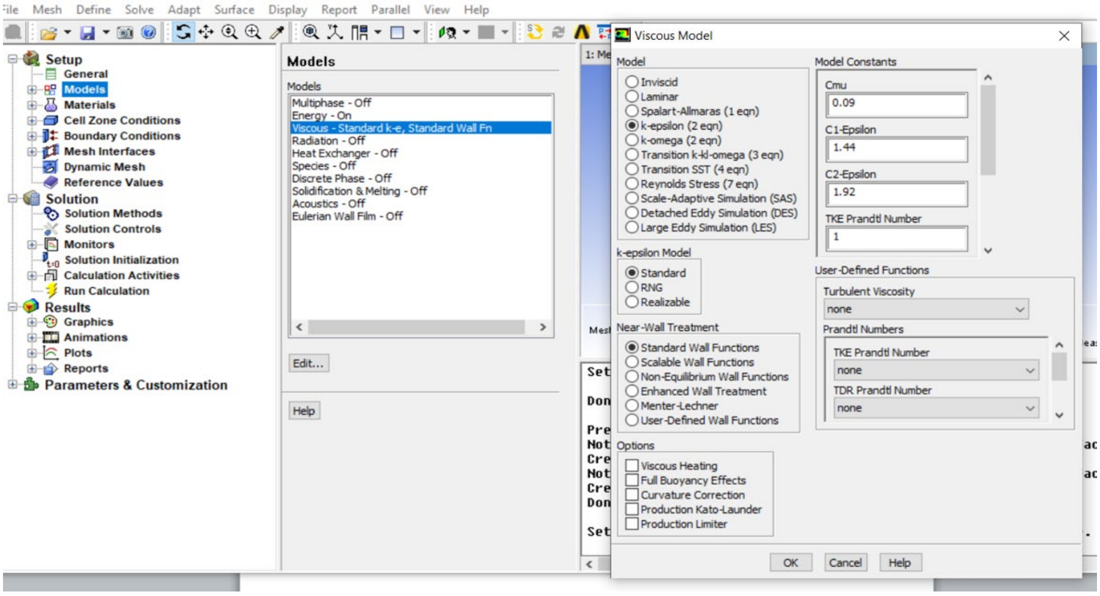


Fig : 50

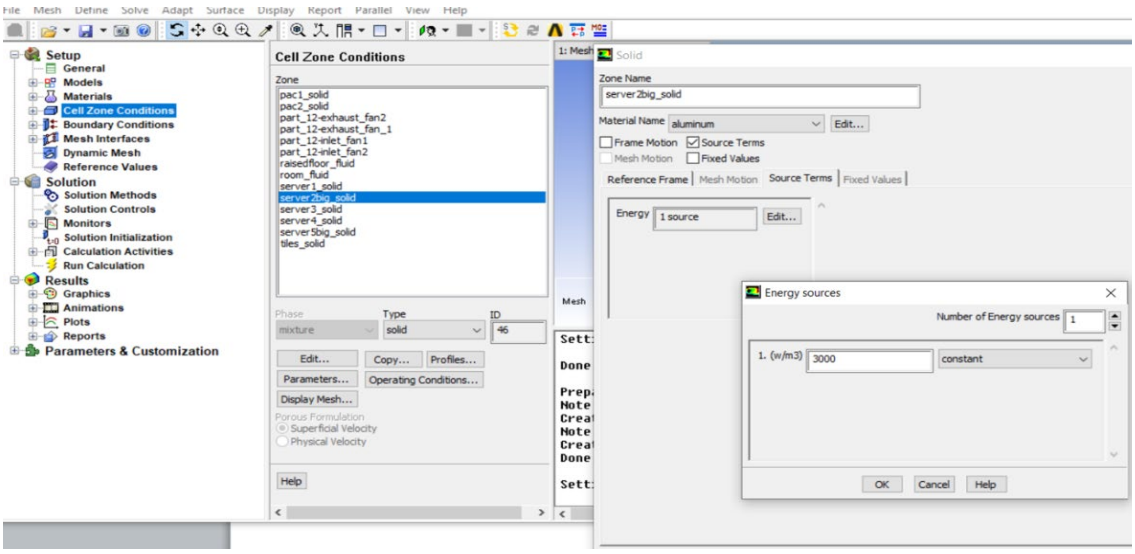


Fig : 51

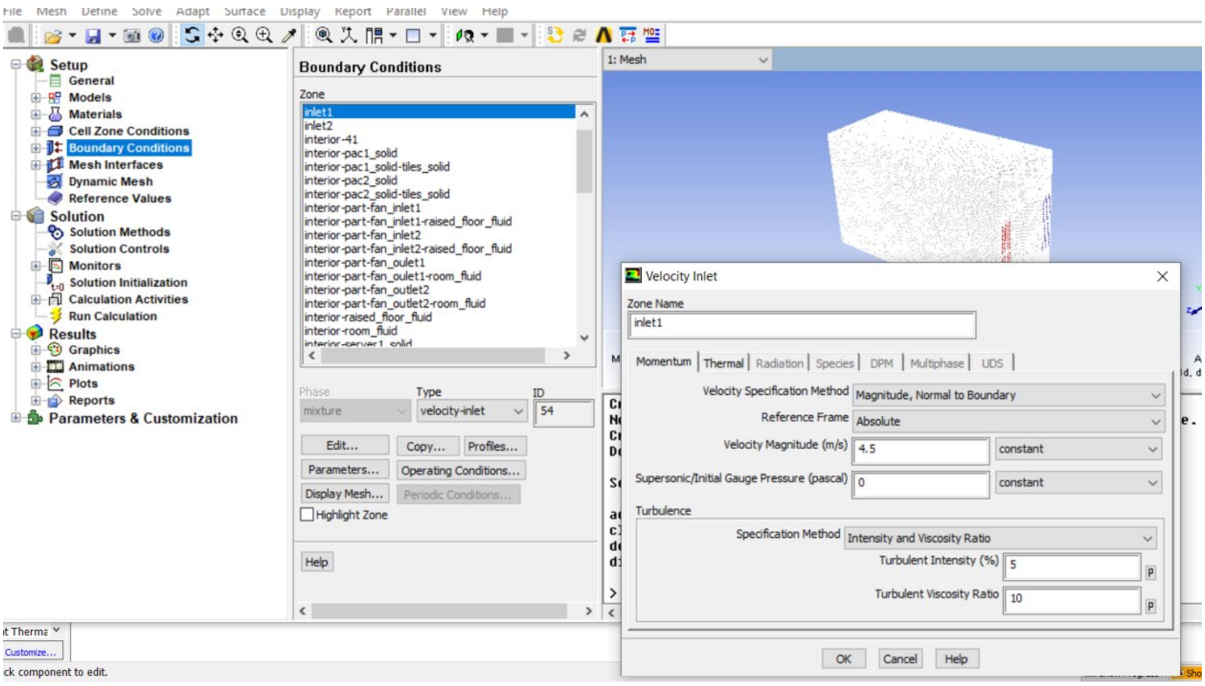


Fig : 52

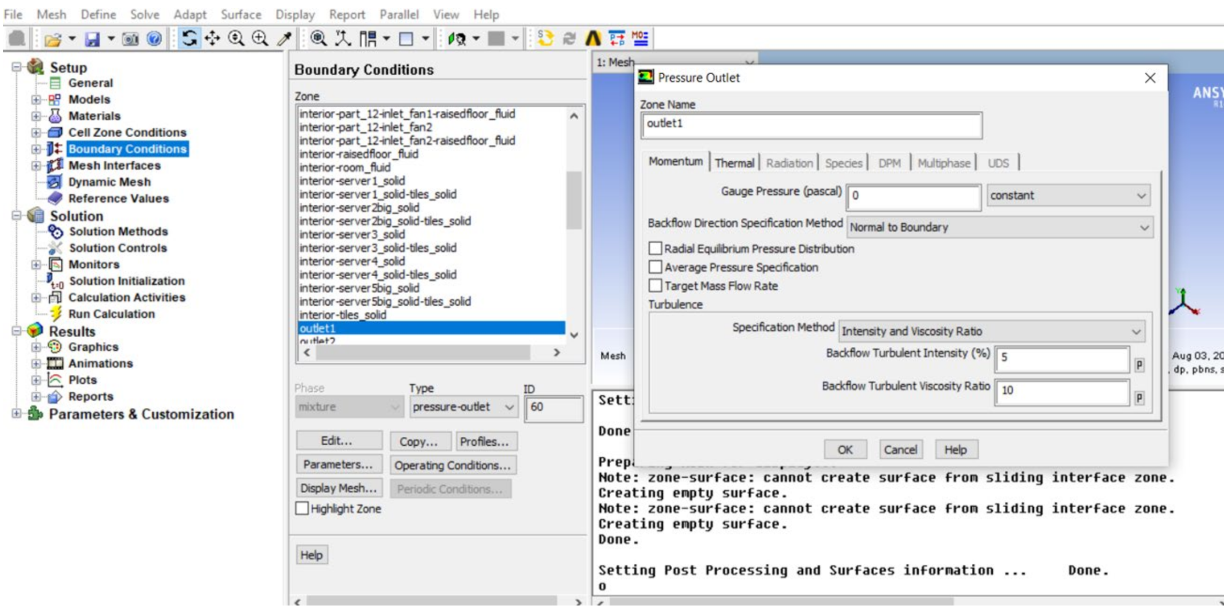


Fig : 53

4) Result & Discussion:

i) Temperature contour:

Fig 54 shows temperature contours of all servers.

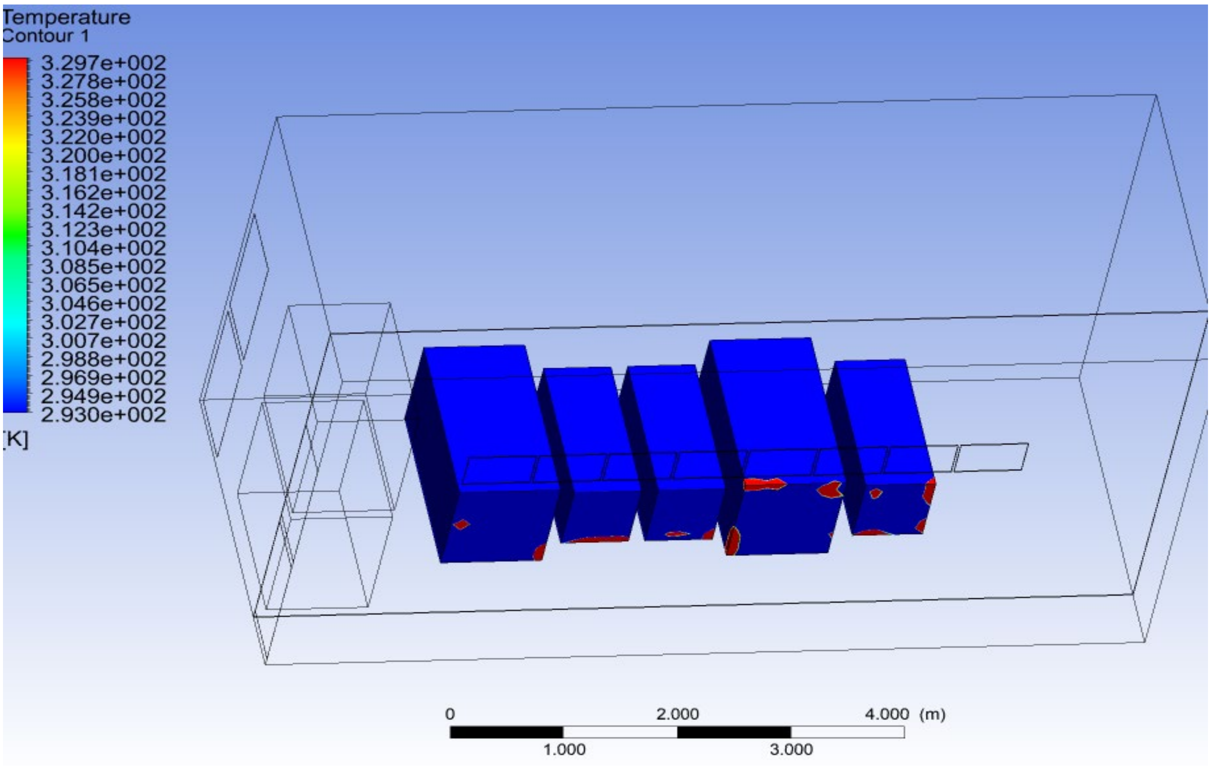


Fig : 54

Out of five servers server 1 and server 2 which is far away to the CRAC's are found with more hotspots. Then servers 3,4 & 5 are have the equal hotspots.

From fig 55 and 56 are represent the velocity vectors in the raised floor and at the vents. From fig 55 anyone can clearly identify that the cold air coming from the inlet-1 is moving towards to the servers and then hitting the walls of the room and making a **swirl type** of flow. There are totally two swirl type of flows are there. Major vectors are moving towards the servers making bigger swirl flow and minor vectors are moving away from the server side making smaller swirl flow. After making a swirl action the air will enters through the vents that will be visualize in fig 56.

From fig 56 the 2, 3, 4 & 8 vents are having higher velocity's. Arrow marks of the velocity vectors are clearly visualize. Vent 8 is nearer to CRAC the cold air passing to it will automatically attract more air after that the is moving towards the servers

which are heat generating sources. So 2, 3 and 4 will have higher velocity's. as per discussion for case study-1 here also the cold air is making swirl type of flow. From fig 57 &58 clearly visualize that at vents 7,8 vectors are moving away from the servers and then for remaining vents vectors are moving towards the servers, this is clearly because of swirl flow.

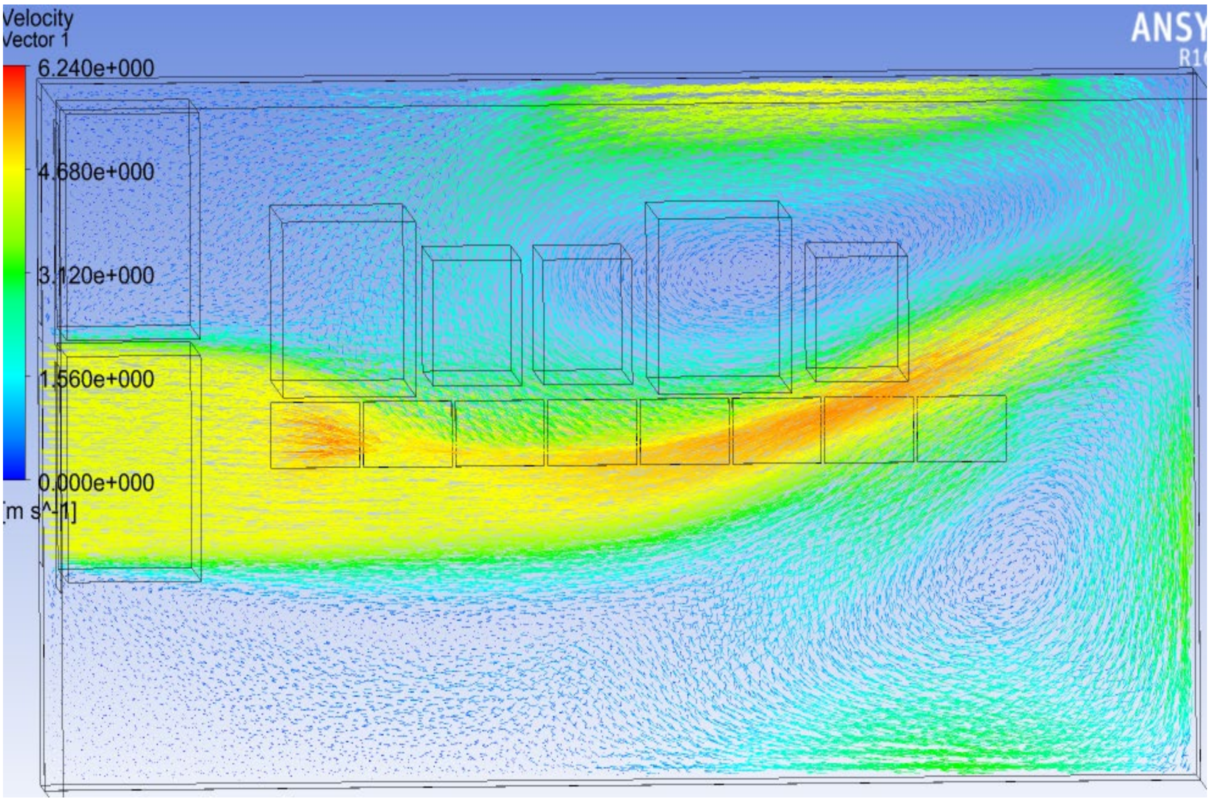


Fig : 55

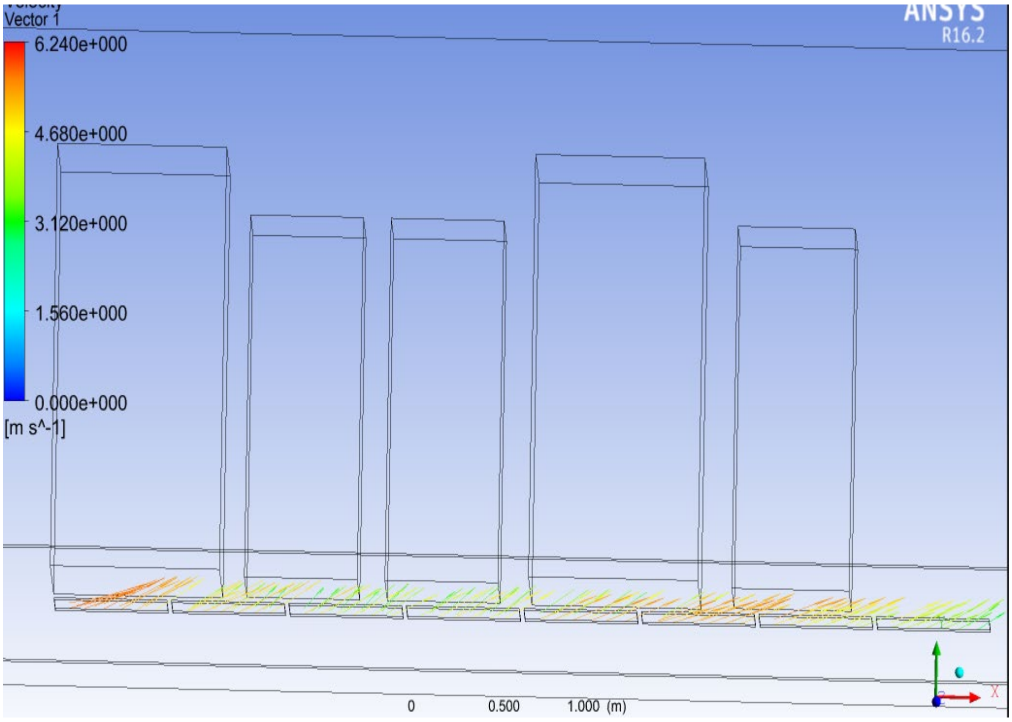

Velocity
Vector 1
6.240e+000
4.680e+000
3.120e+000
1.560e+000
0.000e+000
[m s^-1]
ANSYS
R16.2
0
0.500
1.000 (m)
X

Fig : 56

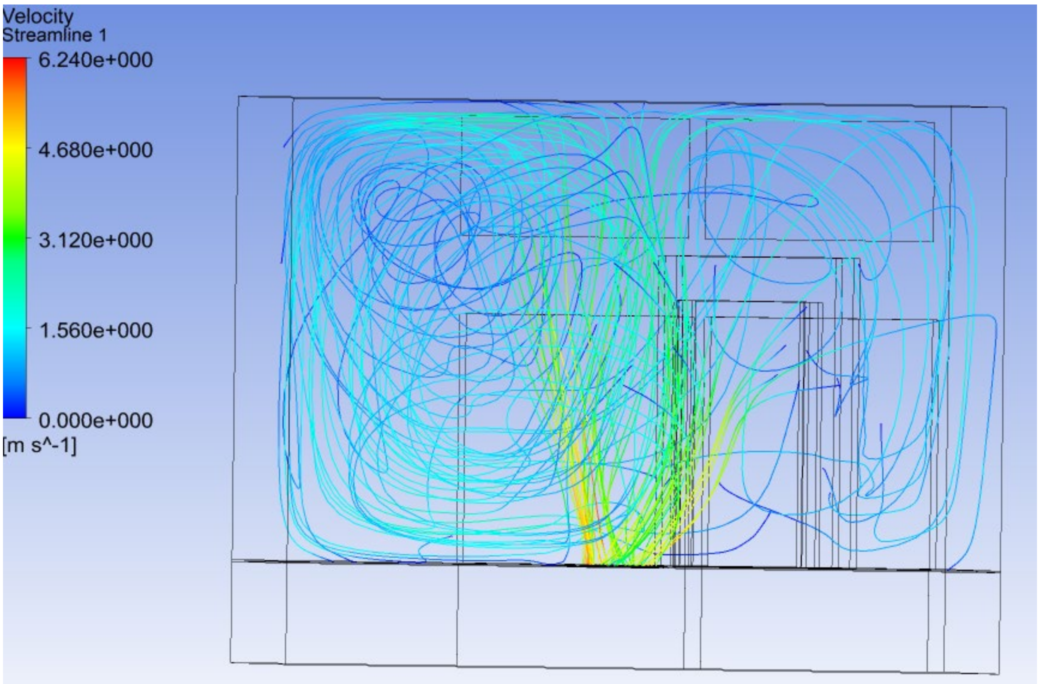

Velocity
Streamline 1
6.240e+000
4.680e+000
3.120e+000
1.560e+000
0.000e+000
[m s^-1]

Fig : 57

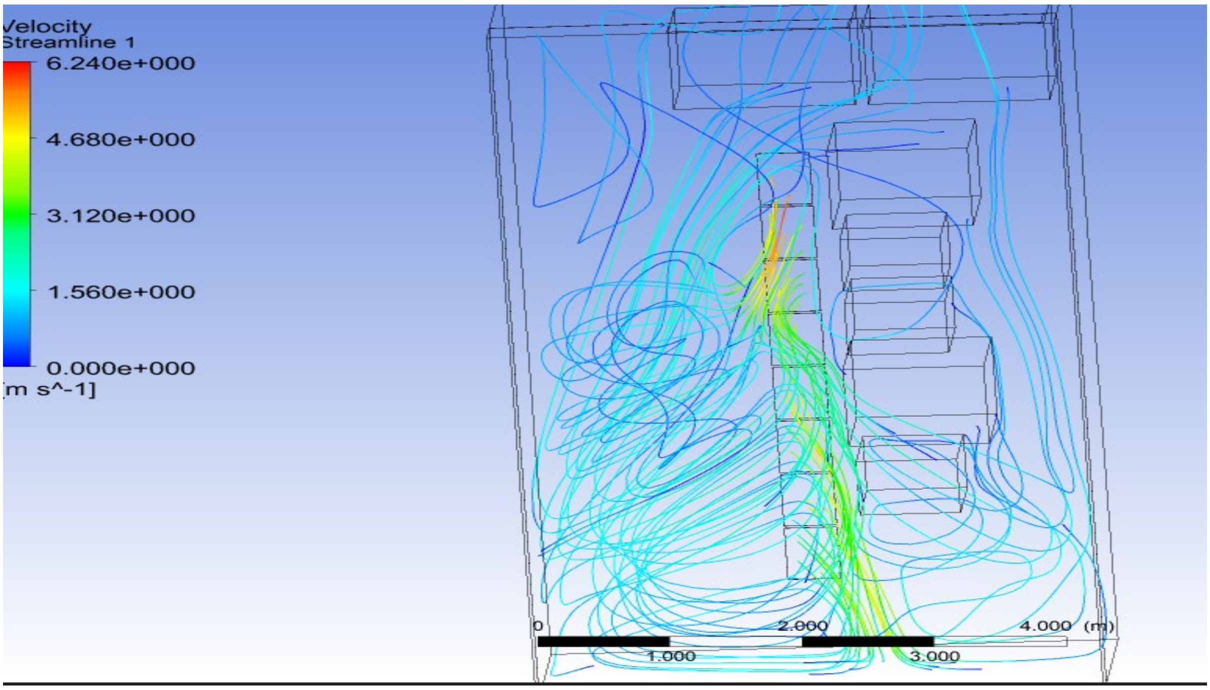


Fig : 58

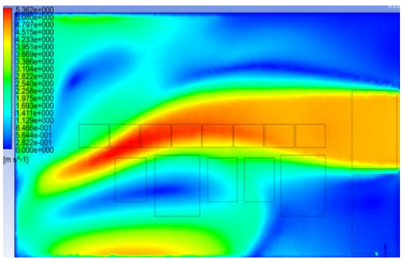


Fig : 59

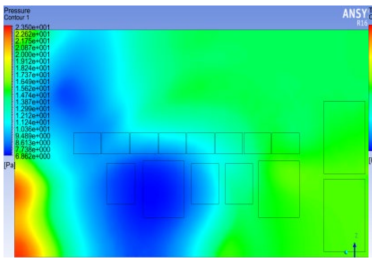


Fig : 60

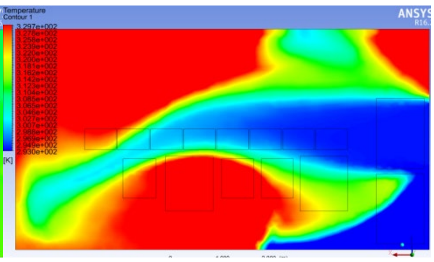


Fig : 61

Also from figures 59, 60 and 61 which represents velocity, pressure and temperature contours in raised floor. From these figures also can visualize that there is lack of cooled air supply for server-1 and server-2.

ii) <u>Velocity Vectors</u>:

Fig 55 represents velocity vector in raised floor. Already discussed that velocity vector in raised floor will form a swirl type of action. Because of the heat generating sources the cold air will attracted towards the servers.

Fig 56 shows velocity vector at vents. Again because of the swirl action the velocity vector at vents are towards the server side at vent 1 to 6 and for vents 7 to 8 are away from the server side.

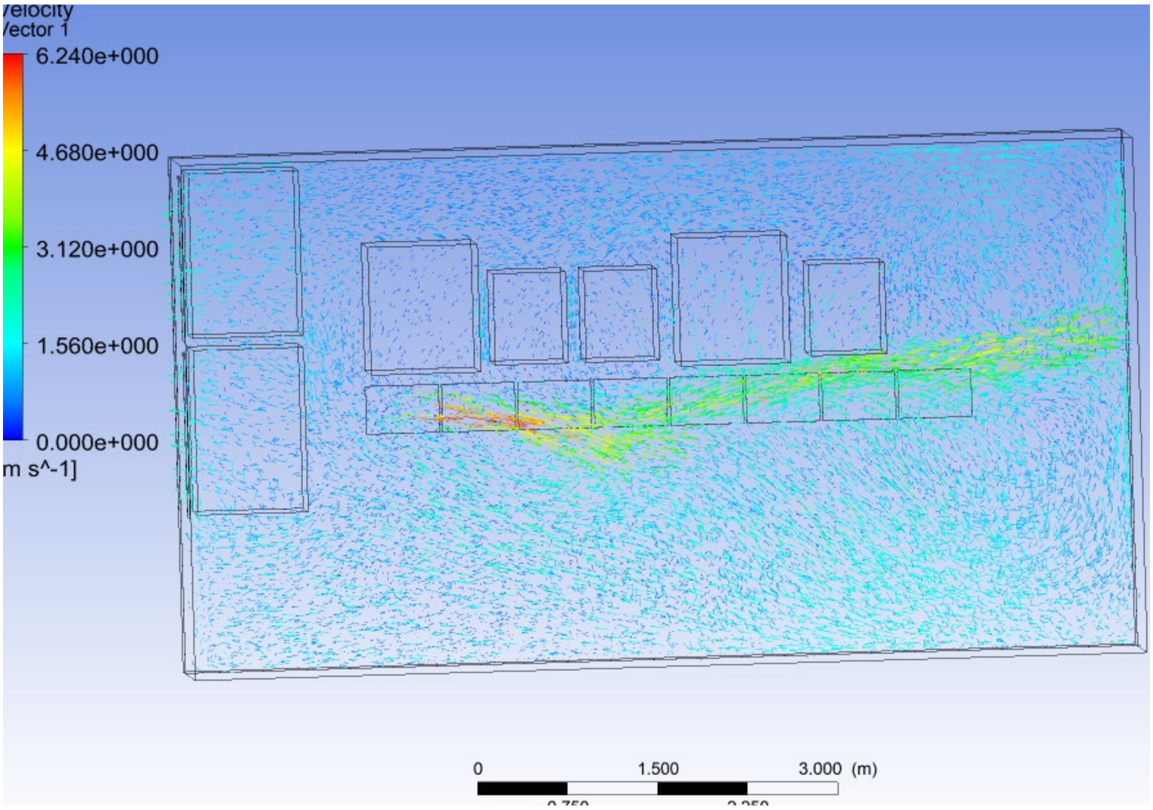


Fig : 62

Fig: 62 represents the velocity vector inside the room. From the fig can visualize that velocity vector at vents having higher velocity compared to the reaming vectors spread in the room.

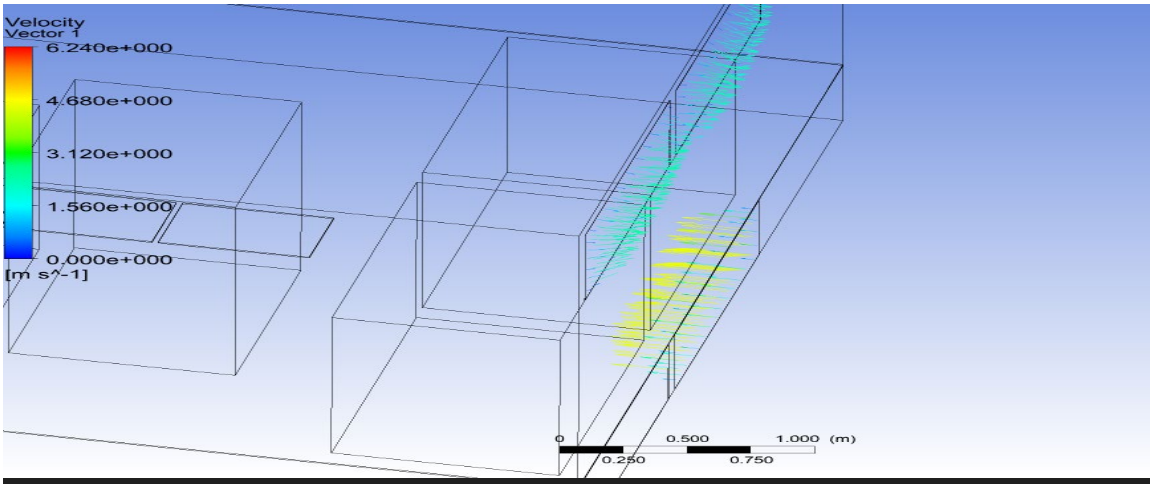


Fig : 63

Fig 63 shows that velocity vectors at inlets and outlets. At inlet 1 can identify the velocity entering into the server which is the input given in the fluent i.e 4.5 m/s. whereas at inlet -2 there is zero velocity because of standby of CRAc-2. At outlets velocity coming out of them can clearly visualize with arrow marks.

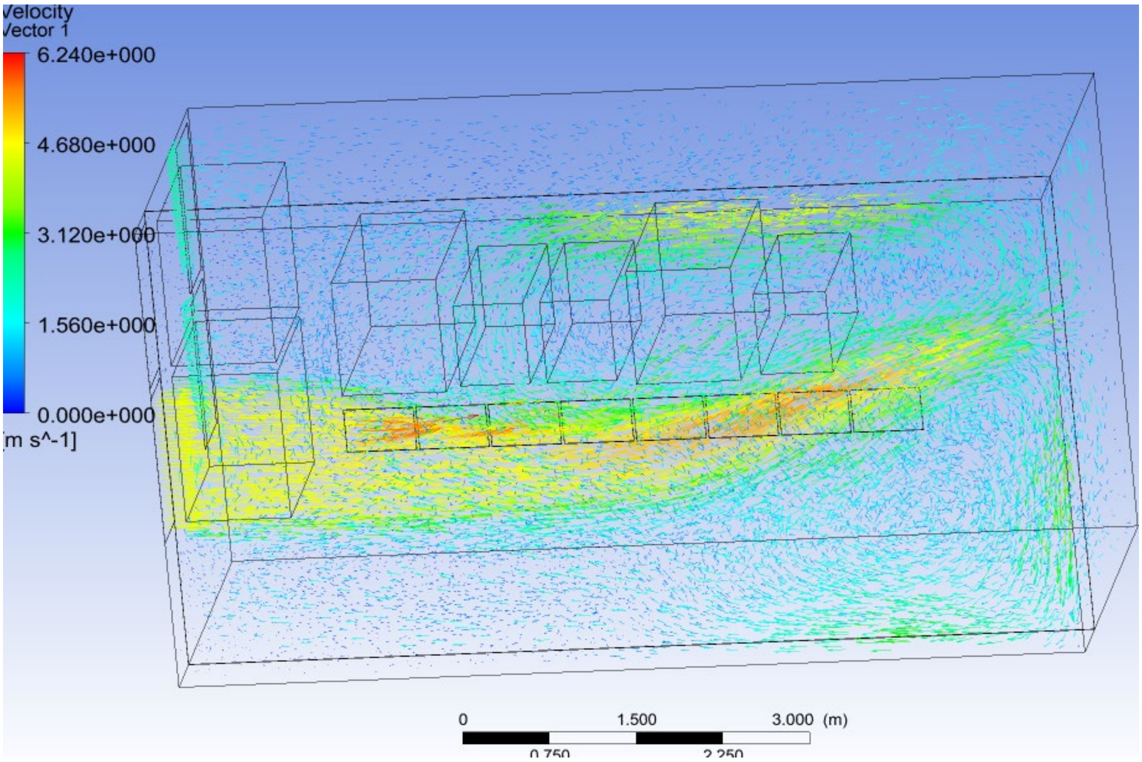


Fig : 64

Fig 64 shows velocity vector of entire data centre. Here can anyone easily identify the different velocities at different locations. At inlet the input velocity will be increased at the vents and again decreased inside the room finally coming out of the outlets increased again.

iii) <u>Velocity streamline :</u>

Fig 57 & 58 shows the velocity streamlines at vents. The velocity streamlines coming out of the vents are having the highest velocity compared to all other locations. Because vents are actually acting like as a nozzles. Automatically nozzle increases the velocity. But already discussed about swirling action that formed in the raised floor velocity streamlines at vents 7 to 8 moving away from the server side and at vents 1 to 6 moving towards the server sides.

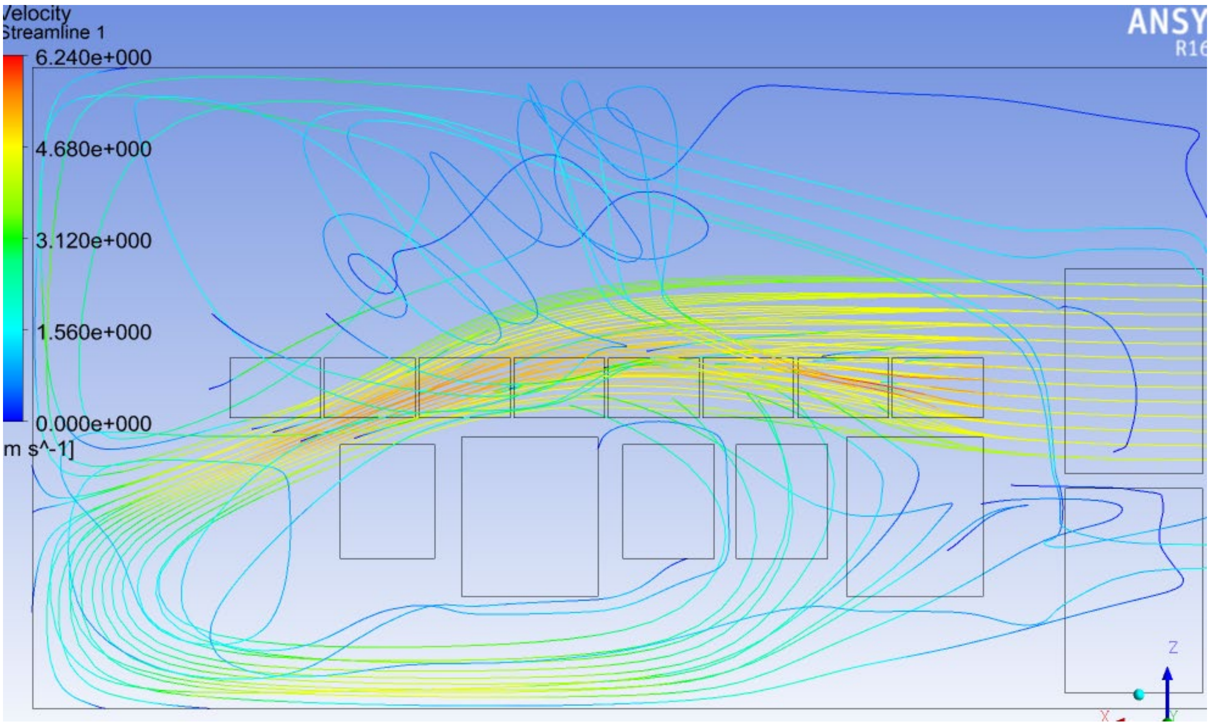


Fig : 65

Fig 65 shows the velocity streamlines at inlet-1. Inlet-1 velocity input given as 4.5 m/s and after entering into the raised floor it forms swirling type of flow. There are totally two swirl flows are formed. After that the air will enters to the room through the vents.

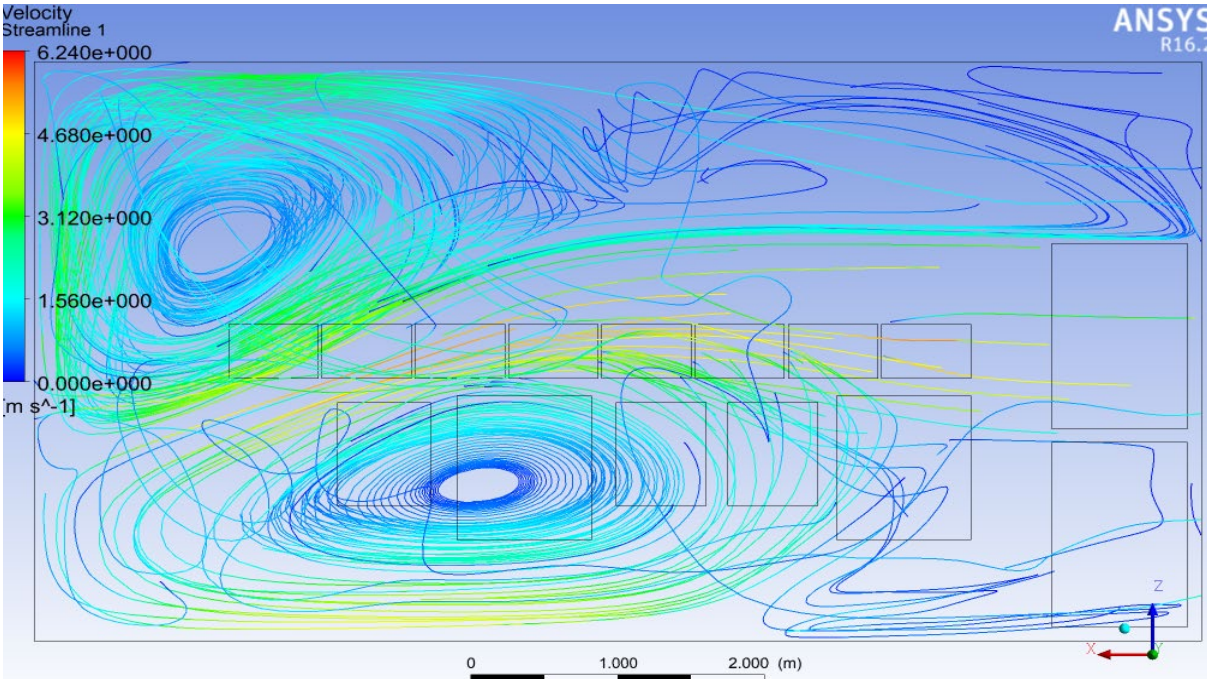


Fig : 66

Fig ; 66 shows the velocity streamlines in raised floor. Here there is no velocity streamline from the inlet-2 as it is idle.

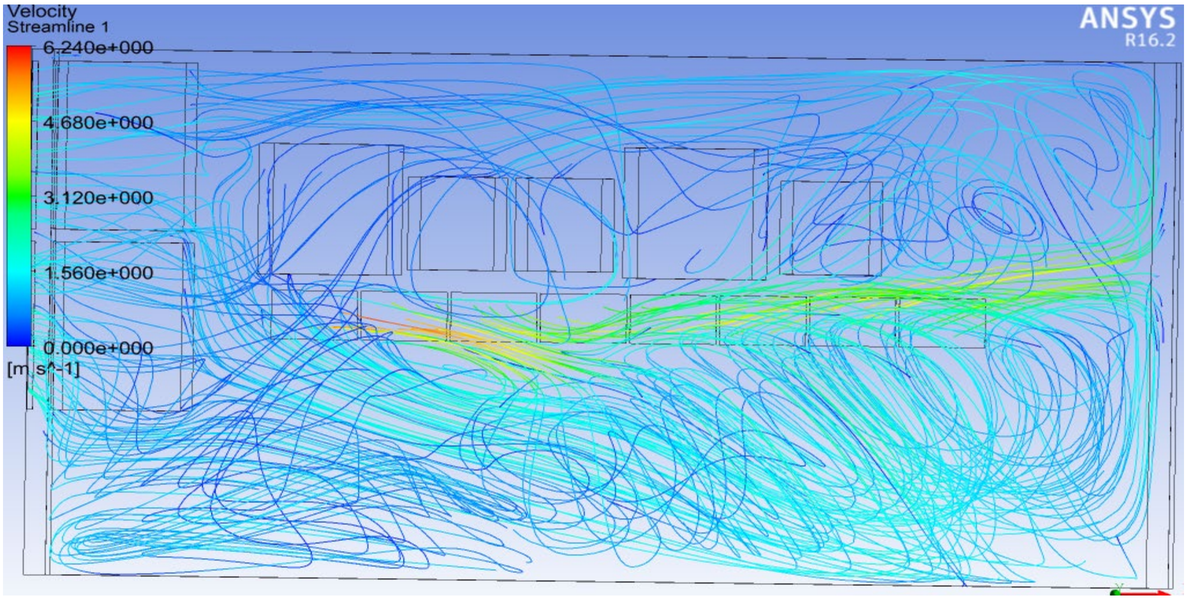


Fig : 67

Fig 67 shows the velocity streamlines in the room. The velocity streamline coming from the vents which are having the higher velocity and then circulating the entire room the velocity decreases. From the fig can anyone visualize that the velocity streamlines are hitting the room walls and recirculation in the entire room. Because of this the velocity decreases and when it is coming out of the outlets velocity increases.

v) **Contours of Velocity, Pressure and Temperature at different locations in XZ-plane :**

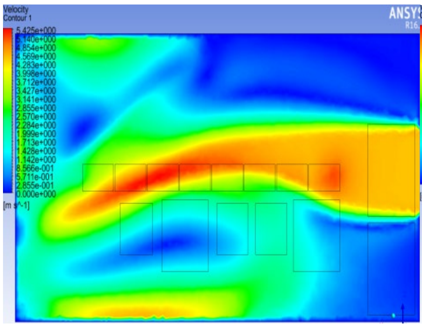
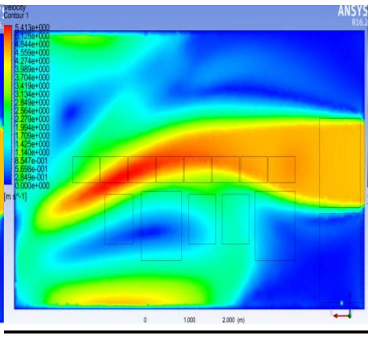
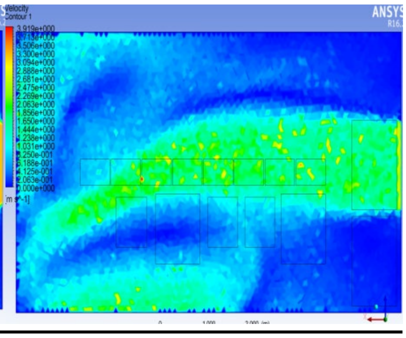




Fig : 68 XZ@ -150 mm Fig : 69 XZ@ -300 mm Fig : 70 XZ@ -580 mm

Fig 68, 69 and 70 are velocity contours at -150 mm, -300 mm and -580 mm respectively from the XY plane. These planes all are considered in the raised floor. From the figs observe that as the depth of raised floor increases from XZ-axis, velocity is decreasing.

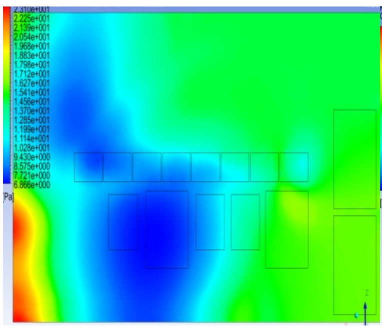
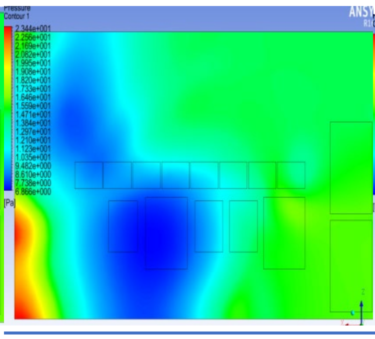
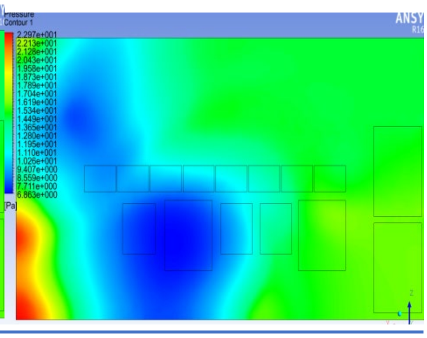




Fig : 71 XY@ -150 mm Fig : 72 XY@ -300 mm Fig : 73 XY@ -580 mm

Fig 71, 72 and 73 are pressure contours at -150 mm, -300 mm and -580 mm respectively from the XY plane. These planes are also considered in the raised floor. From the figs observe that as the depth of raised floor increases from XZ-axis, pressure is increasing.

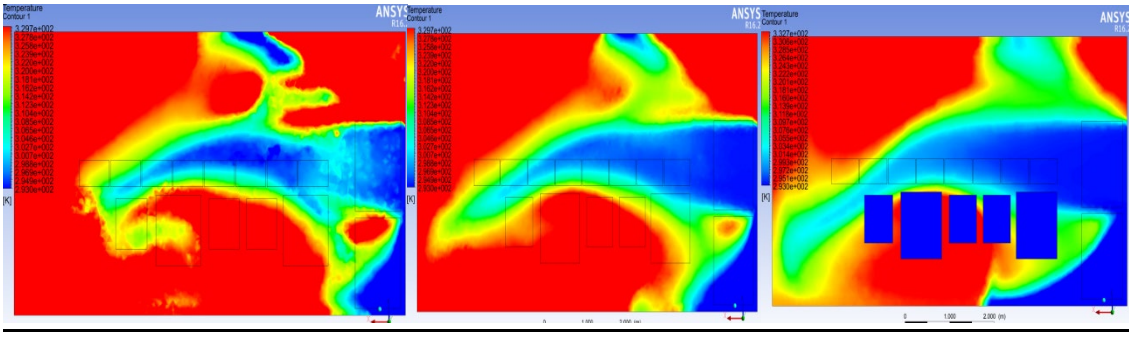


Fig : 74 XY@ -150 mm   Fig : 75 XY@ -300 mm   Fig : 76 XY@ -580 mm

Fig 74, 75 and 76 are temperature contours at -150 mm, -300 mm and -580 mm respectively from the XY plane. These planes are also considered in the raised floor. From the figs observe that as the depth of raised floor increases from XZ-axis, hotspots are decreases.

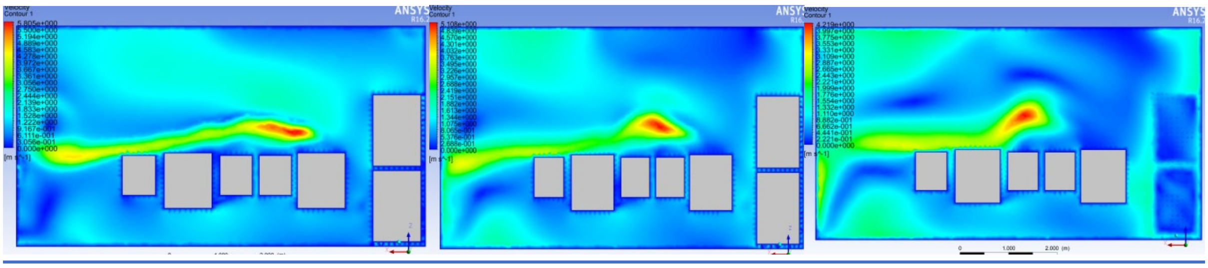


Fig : 77 XY@ 500 mm   Fig : 78 XY@ 1000 mm   Fig : 79 XY@ 1500 mm

Fig 77, 78 and 79 are velocity contours at 500 mm, 1000 mm and 1500 mm respectively from the XY plane. These planes all are considered in the room. From the figs observe that as the height of room increases from XY-axis, velocity is decreasing.

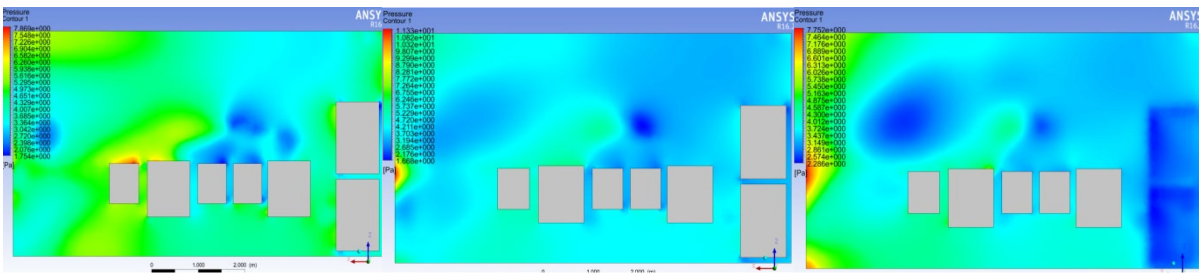
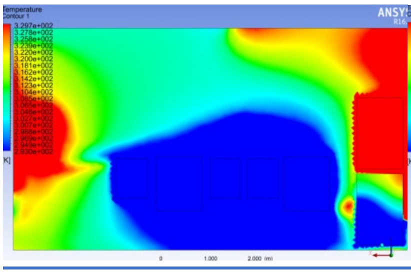
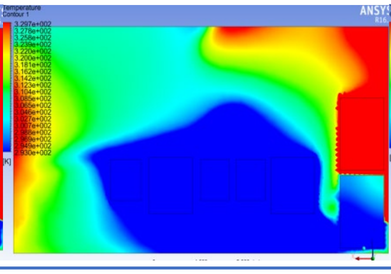


Fig : 80 XY@ 500 mm   Fig : 81 XY@ 1000 mm   Fig : 82 XY@ 1500 mm

Fig 80, 81 and 82 are pressure contours at 500 mm, 1000 mm and 1500 mm respectively from the XY plane. These planes all are considered in the room. From the figs observe that as the height of room increases from XY-axis, pressure is decreasing.





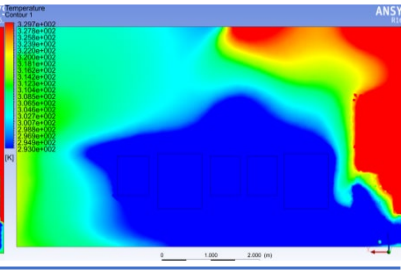


Fig : 83 XY@ 500 mm Fig : 84 XY@ 1000 mm Fig : 85 XY@ 1500 mm

Fig 83, 84 and 85 are temperature contours at 500 mm, 1000 mm and 1500 mm respectively from the XY plane. These planes all are considered in the room. From the figs observe that as the height of room increases from XY-axis, hotspots are decreasing

CHAPTER-6

TECHNIQUE FOR CONTROLLING THE FLOW OF COLD AIR IN THE DATA CENTRE IN RESPONSE TO LOAD VARIATIONS IN THE RACKS

The analysis of temperature variation utilising ANSYS simulation package will lead to the identification of HOTSPOTS inside the Data Centre. These hotspots are generated as a consequence of variation of heating loads in the racks.

Upon the identification of these hotspots, the flow of cold air to be supplied to different areas of different racks is to be controlled. This can be achieved in following ways:

a) Varying the air quantity from each CRAC in response to the return air or hot air temperature. This can be achieved by installing thermostats which will sense the hot air temperature at the inlet to the CRACs and control the rotational speed of the blower fan by using a VFD (variable Frequency Drive) system.

b) Another method will be to sense the hot air temperature coming out of the racks by a modulating thermostat which will send signal to a modutrol motor that operates the variable air flow dampers installed in the floor grills through which supply air to the racks are coming out.

CHAPTER-7

CONCLUSION

Using CFD simulation for computing the results gives accurate results and the temperature and velocity profiles inside the data centre can be visualized. CFD simulation will give Velocity, Pressure and Temperature profiles, velocity vectors, velocity streamlines. This visualized data is very much useful for finding the hotspots, air flow rate to be supplied to the server racks.

In this study the detailed investigation is done on two Data Centres with the help of ANSYS CFD simulation technique. Old design Data Centre has observed that lack of air supply to the racks whereas modified design has observed that all server racks are effectively cooled. The temperatures measured at the server racks are in the limit of ASHRAE guidelines [19].

Detailed study is conducted in the raised floor and above the floor with the help of velocity, pressure and temperature profiles are obtained at different locations. In raised floor going deep to the floor velocity decreases and pressure increases. Hotspots decreases. Whereas in the above floor the height from the origin increases both pressure and velocity decreases. Hotspots also decreases.

Finally the hotspots are forming mainly at the bottom of the server racks that is nearer to the raised floor.

Based on the above outcomes the supply air to the individual racks can be controlled automatically as described in chapter-6.

CHAPTER-8

SCOPE OF FURTHER WORK

- CFD simulation can be performed by changing the boundary conditions. The boundary conditions like inlets and outlets can be given in the CRAC units.
- Different turbulence models like K $-\varepsilon, RNG\ k-\varepsilon\ and\ k-\omega$ can be studied for simulation purpose. Which model gives better optimisation can be identified.
- Different flow rates can be considered, which flow rate is giving better optimisation also be studied.
- In this thesis only one CRAC is considered other kept as standby. But utilising two at a time with lesser flow rates also be used. So that optimisation of cold air will be studied .
- Both CRAC position in the designs are kept on one side only. Position of the CRAC will be changed, like keeping two are opposite to each other. Also if there are more than two can place on every side of the room. So that the cold will enters all sides of the raised floor. Proper cooling of the servers are happening can be studied.
- Study will be done by changing the server's position like placing all are in square type arrangement so that vent will be provided inside of them and fan will be provided in the room opposite to the vent.
- There is no separate cold aisle and hot aisle arrangement considered in this design. The hot air can mix up with the cold air and cooling effectiveness will be reduced and cost will be increased. So aisle arrangement can be considered and can study how the cooling is effectively used and cost will be reduced.
- The entire Data centre purely depends on how the airflows in the raised floor. The more study can be done how effectively the air can be managed in the raised floor.
- In raised floor in front of the vents by providing the fans with some inclination towards the vents the flow rate to the server racks can be increased.
- Change in the layout of the racks on the raised floor can be easily addressed by carrying out simulation analysis to specify the hotspots and accordingly supply air flow can be controlled.

CHAPTER-9

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